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EQUIPMENT DEVELOPMENT & TEST REPORT 7120-5

SNOWMOBILE NOISE

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Equipment Development and Test Report 7120-5

SNOWMOBILE NOISE

by

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ABSTRACT

The snowmobile has become a significant source of noise pollution in winter forest areas, and thus the cause of many complaints. This report covers the results of tests to determine the effects of snowmobile noise on the environment and on the snowmobile operator. The operator's average noise dosage and temporary loss in hearing acuity were measured. A winter test procedure to determine snowmobile noise is proposed.

Findings indicate that noise levels were higher than can be tolerated. The impact on the environment is high. The noise level at the operator's ear exceeds Occupational Safety and Health Standards for employees, and if exposure is continued over a period of time, hearing loss would be expected. Protection is advised for employees.

ACKNOWLEDGEMENT

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KEY WORDS: Noise, Snowmobile, Hearing Loss.

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A report on ED&T Project No. 2210 -
Off-road Vehicle Noise Control -
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INTRODUCTION

The Equipment Development Center at San Dimas has undertaken the measurement and evaluation of noise created by a broad range of off-road vehicles (18). One of the most common off-road vehicle noise sources is the snowmobile. Virtually unknown 10 years ago as a recreation vehicle, the snowmobile is now sold at the rate of over one-half million units annually. Snowmobiles have elicited a great deal of attention from conservation groups and land managers, and the press has dealt with them extensively. They are operated in great number on National Forest lands, and it is unlikely that their rate of growth in popularity will slacken in the immediate future. The objective of the investigations described in this report was to measure the potential hearing damage and environmental impact caused by the noise from these vehicles.

To fulfill these objectives four separate types of measurements were made: the overall machine noise measured at a distance of 50 ft, the sound level at the operator's ear, the sound exposure dosage received by the operator, and the amount of temporary threshold shift of the operator's hearing as a result of snowmobile operation. Measurement of these four dimensions was intended to give a fairly complete picture of the snowmobile noise problem.

TEST PROCEDURES

In order to obtain the data required for the development of this report, a variety of test procedures and instrumentation were required. No attempt has been made to describe each instrument in detail. However, a general description of the instrumentation and method of measurement of each test procedure is provided. For the discussion that follows the reader should be familiar with common acoustic terminology and basic acoustic theory. For a review of acoustic theory and terminology, the reader may wish to study references 1 and 2.

Measurement of Machine Noise at 50 ft

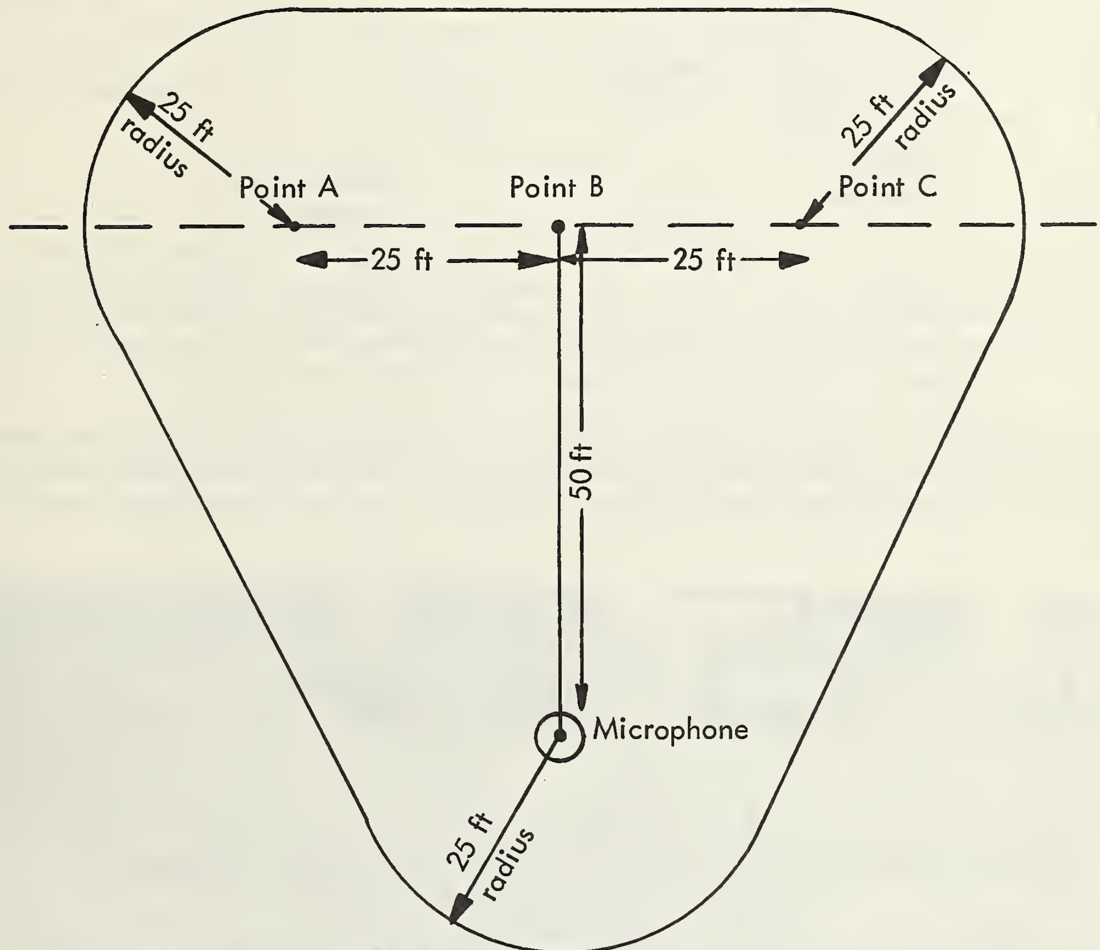
The snowmobiles used as test vehicles were obtained from volunteers at the Lolo Hot Springs, Montana, test site. This site is a popular point of embarkation for snowmobile trips. Twenty-five snowmobiles were tested over a period of approximately 3 weeks. The test snowmobiles are listed in the results section in table 1, p. 9 by make and model. No attempt was made to determine whether the machines tested were representative of the total snowmobile population in the country.

Sound levels were measured at a distance of 50 ft from the snowmobiles for two reasons. The first was that it is the distance specified by the Society of Automotive Engineers SAE J192 test procedures, which is the most widely recognized measurement method for snowmobiles. This is the best reference point to start determining the environmental impact from snowmobile noise. The second reason was to develop a winter snow test procedure and correlate it with SAE J192. The latter is a carefully controlled Qualification test, not suitable for field use.

Figure 1 shows the pack snow test area at Lolo Hot Springs. Figure 2 is a diagram showing the physical dimensions of the course. The tests were conducted by driving a snowmobile along the test course at 25 mph to point A. When the operator reached

Figure 1. Test area, packed snow condition, at Lolo Hot Springs.

point A, the throttle was fully opened, and the snowmobile was accelerated past point B to point C, where the throttle was closed. This method of sound measurement hereafter is referred to as the "Forest Service Snowmobile Winter Test Procedure" (FSSWTP). Two or more runs were made on each snowmobile as permitted by the owners. For some selected snowmobiles, test runs were made throughout the entire 3-week period, under various snow and atmospheric conditions, to determine the effects of these conditions on sound levels. Background levels were monitored throughout the test period and measured a minimum of 10 dBA below the test levels. Appendix 3 cites the details of the winter test procedure developed for this study.



COURSE REQUIREMENTS

Uniform level course between points A & B.

No obstructions within boundary shown.

No obstructions higher than 3 ft within 50 ft of points A, B, & C, or microphone.

Figure 2. Diagram, drive-by test course.

Figure 3 shows a schematic diagram of the instrumentation system used to measure the snowmobile noise as the vehicle passed 50 ft away from the microphone.

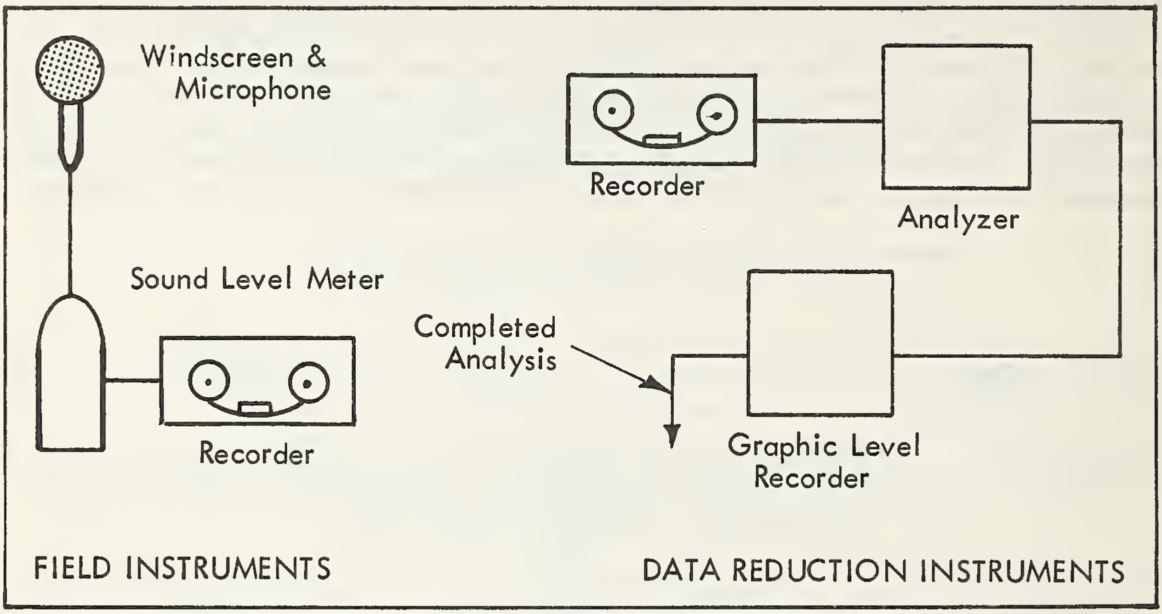


Figure 3. Drive-by noise measuring instrumentation system.

The microphone, B&K type 4145, is protected with a windscreen. This windscreen prevents the generation of extraneous wind noises. The microphone signal is amplified by the Precision Sound Level Meter, B&K 2204. The sound level meter contains

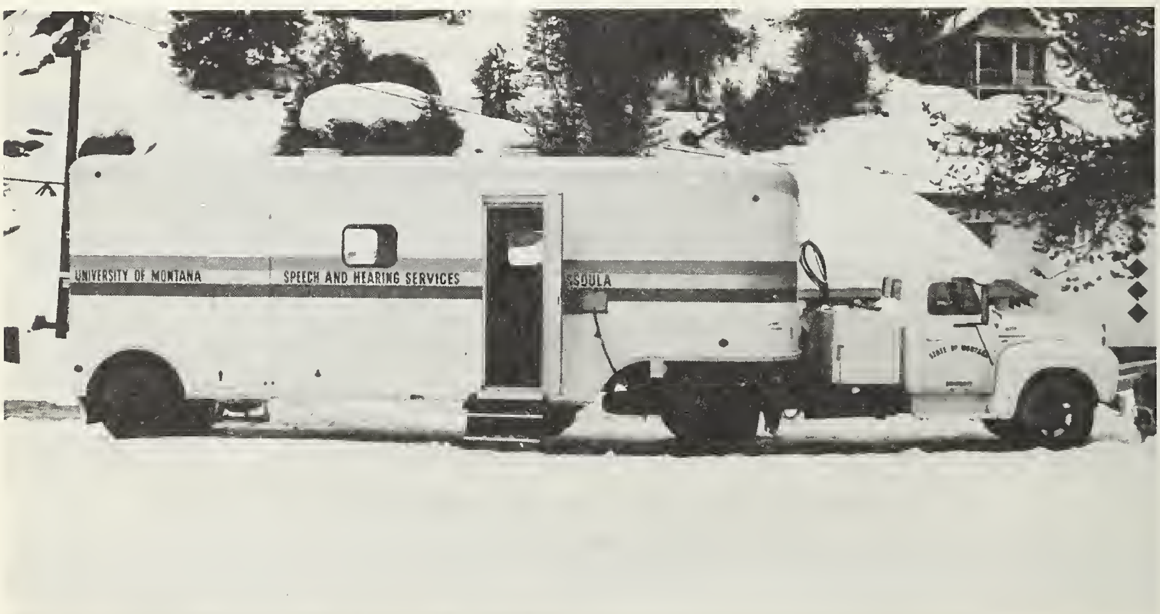


Figure 4. University of Montana mobile speech and hearing clinic.

an amplifier that boosts the microphone signal to a level that can be recorded on the Kudelski Nagra III tape recorder. This instrumentation was used in the field; that is, these are the tools that were taken to the snowmobile. The sound level meter and tape recorder were housed inside the University of Montana's mobile speech and hearing clinic (see fig. 4). The microphone was placed on a tripod next to the test track in the measurement position.

After the sound level recordings were made, data analysis was carried out by taking a section of the recording tape, splicing it into a loop, and repeatedly playing this back on the recorder. This repeated signal was fed into a B&K analyzer, type 2114.

This instrument, basically a frequency filter set, provides a 1/3 octave band analysis of the noise, which is fed into a graphic level recorder. The B&K analyzer also has an A-filter, so A-weighted measurements of the test noises were made.

At-Ear Sound Level Test

A few at-ear level measurements were made using just the sound level meter. Four snowmobiles were tested, with primary emphasis on one machine under a variety of snow and atmospheric conditions, to determine their effects. Figure 5 shows the method of obtaining the at-ear sound level data. Only a B&K type 4145 microphone with windscreen and the B&K 2204 Precision Sound Level Meter were used. This is part of the instrumentation shown in figure 3. No tape recordings were made because of the difficulty of mounting a recorder on a snowmobile. The procedure was for the snowmobile passenger to hold the sound level meter in close proximity to the driver's ear, and then to his own, while an experienced operator accelerated the snowmobile at full throttle from 0 to 35 mph. The microphone position was varied throughout the range of positions normally encountered by operators and passengers during snowmobile operation.

Figure 5. Measuring operator's at-ear noise.

Dosage or Cumulative Exposure Measurements

For these tests the snowmobiles were operated by Forest Service personnel in a typical recreational pattern.

The information gathered by this test was the cumulative dosage of the sound level as it varies with time. The instrumentation already described can provide complete spectral information, but only maxima in the temporal domain. It can determine peak intensities, but cannot relate them to time and duration. Thus, dosage cannot be measured or computed with these instruments.

Dosage is important from the standpoint of both environmental pollution and hearing health. Therefore, a special instrument was developed that records the amount of time that the operator's ear spends in each of several "amplitude ranges." The instrument, called a noise exposure meter, is shown schematically in figure 6. Figure 7 is a photograph of the instrument mounted on a snowmobile and shows the hard-hat mounted microphone. The instrument circuits are, in essence, a series of clocks, each of which "turns on" when its lower sound level is met, and "turns off" when its higher sound level is exceeded. Thus, each of the clocks records the amount of time that the microphone (in this case, located at the snowmobile operator's ear) is exposed to a given "amplitude range." At any given point in time, only one clock is running. The sum of the readings of all clocks equals the total instrument on-time, which can be checked against a "total on time" clock.

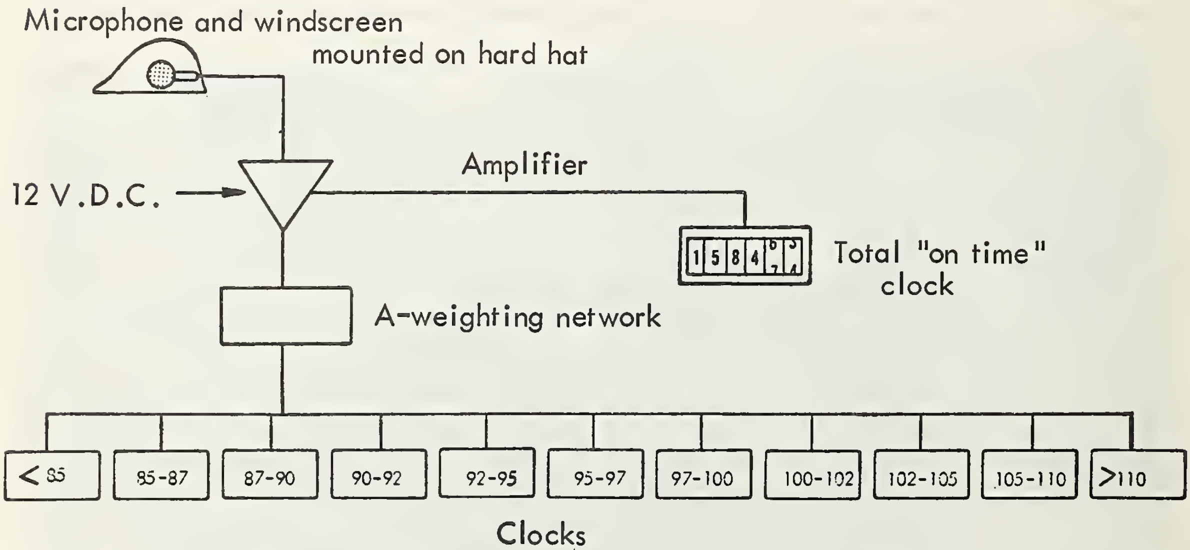


Figure 6. Schematic diagram, noise exposure meter.

To assure the accuracy of these data, the instruments were field calibrated before and after each data gathering run. A B&K Pistonphone was used to calibrate the sound level meter-recorder system. To calibrate the exposure meter, an Insert

Voltage Calibrator (B&K type 167S) and a Portable Acoustic Calibrator (B&K type 4230) were used.

Figure 7. Exposure meter mounted on snowmobile, and microphone mounting.

Operator Temporary Threshold Shift Test

The snowmobiles used for measuring drive-by noise amplitude at a distance of 50 ft were also used to determine operator's temporary threshold shift, or temporary loss in hearing acuity. The temporary threshold shift caused by exposure to snowmobile noise was evaluated on a group of 40 people, which was divided into two sub groups. One, the "volunteer" group consisted of 24 snowmobile operators who had no connection with the test program; that is, they were members of the general populace who were using their snowmobiles for recreation in the Lolo Hot Springs area. The second, or "controlled" group, consisted of 16 graduate students from the University of Montana and technicians from the Equipment Development Center who were participating in the test.

The audiometric work described in this report was performed by members of the University of Montana Department of Speech Pathology and Audiology.

The Tracor Automatic Audiometer Model ARJ-4A, used to evaluate hearing acuity, provides a complete, automated system of aural testing. The audiometer consists of a frequency generator, audio output circuit, and subject-response monitoring system. The subject wears a headset that permits testing each ear at various frequencies, which were slowly increased in volume. A subject-operated switch is used to actuate the recording section of the audiometer to determine the subject's threshold at each frequency. The audiometer tests were conducted in a sound-controlled room of the mobile clinic.

Before he started his machine, each "volunteer" snowmobile operator was given an air conduction threshold test--left ear--using the audiometer described above. He was then asked to ride his snowmobile in a normal manner and record the amount of

time spent on his machine. When he returned to the mobile unit his threshold was again measured, using the same audiometer. The temporary threshold shift was obtained by comparison of pre- and post-noise exposure audiograms.

Students and employees of the Equipment Development Center (the "controlled" group) also received pre-exposure audiograms in the mobile unit. Each then rode a snowmobile (the 1968 Moto-Ski 500) in the area of the mobile unit for 30 min. When each subject returned he was given another audiogram. Again the temporary threshold shift was determined by comparing the before and after noise exposure audiograms.

TEST DATA AND ANALYSIS

Sound Level Measurements at 50 ft

The snowmobile sound and sound pressure levels measured at 50 ft by the winter test procedure, FSSWTP, are shown in table 1. Each level shown is the average of at least two runs, although in most cases three or four runs were used to obtain the average figure shown. Runs were made in both directions, so results for both sides of each machine were averaged. Where more than one identical (model and year) snowmobile was tested, the sound levels shown are averages of all tests. The run-to-run variation at any site on any given day was less than plus or minus 1 dB from the average.

Comparison of SAE and Forest Service Test Procedures

One objective of the work done was to compare sound levels obtained by the FSSWTP at 50 ft with the Society of Automotive Engineers SAE J192 levels for similar ma-

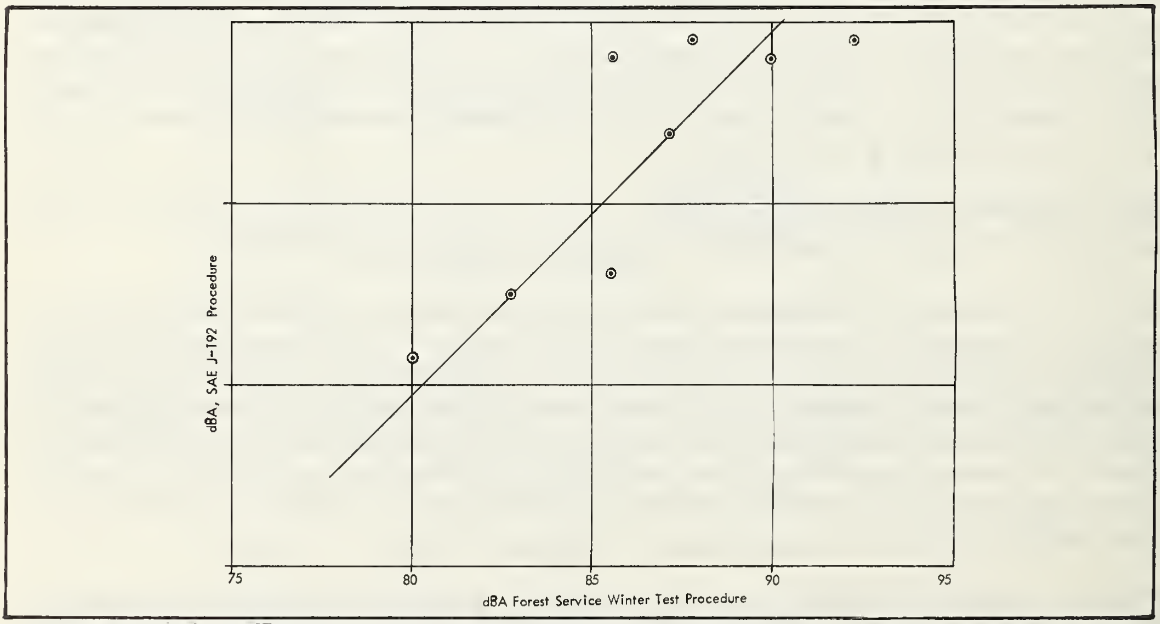


Figure 8. Correlation of FSSWTP test 50-ft sound levels vs. SAE J192 levels.

chines. For those snowmobiles for which SAE J192 results were obtainable from the manufacturers, the correlation curve is shown as figure 8. If linear correlation and a slope of one are assumed, the equation of the correlation line is $L_F = L_S - 1/2$ dBA, where L_F = the level obtained by the winter test procedure in dBA and L_S = the level obtained using SAE J192 procedure. This line has a correlation coefficient of 0.69.

It is obvious that more data are needed to substantiate this correlation. It is likely that sampling error would be somewhat reduced if it were possible to run the same machines through both tests. Figure 8 shows that, although for individual machines it is difficult to determine what the SAE level would be from a test using FSSWTP, the SAE and FS methods yield nearly identical results for the average of all machines tested.

Table 1. 50-ft sound level data, FSSWTP

Manufacturer	Model	Year	Levels	
			dBL_{in}	dBA
Moto-Ski	399	'72	90	82
	399	'71	97	92
	Zephyr	'69	93	87
	500	'68	94	87
Ski-Doo	Elan	'72	87	80
		'71	93	83
	TNT	'72	99	92
		'71	98	88
	Nordic 371	--	92	86
	Olympique	--	95	90
	300	'68	95	90
	Alpine 399ER	'71	82	80
Ski Whiz	---	--	92	86
Polaris	TX	'71	96	91
	Mustang	'68	93	84
Mercury	250E	'69	90	86
Evinrude	Skeeter	'71	96	87
		'67	95	92
Sno-Jet	---	'67	104	99
Raider	400	'71	78	77

All of the machines tested except for the Sno-Jet appeared to be in good mechanical condition with the mufflers attached and operating. However, the machines may get somewhat noisier with age. In any event, the condition of the machines tested was probably representative of the general condition of snowmobiles found in the population. Sound levels reported by the manufacturers were all for new machines.

Engineers in the snowmobile industry often disagree as to the effect of snow conditions on sound levels of snowmobiles. One industry representative reports that the sound level of one machine varies as much as 11 dBA from one snow condition to another and that the same test course can produce results varying as much as 3 dBA between 10 a.m. and 2 p.m. on the same day. He states that some snow conditions produce 50-ft sound levels greater than those obtained on grass with the same machine. A Canadian Government official, on the other hand, states that snowmobiles are always quieter on snow than on grass, and that the difference averages 3 dB.

One possible reason for differences between sound levels measured at 50 ft, as obtained by manufacturers and by the FSSWTP, is the elevation of the test course. A rise in elevation of 1,000 ft causes a loss of approximately 3 percent in engine power. If this reduction in energy output causes a corresponding 3 percent reduction in sound pressure level, a change in test course elevation from 1,000 to 7,000 ft would cause a reduction in sound levels at 50 ft of approximately 2 dBA.

Consistency Between Machines

During the tests, when possible, the sound levels of outwardly identical machines were measured. Table 2 shows 50 ft FSSWTP levels obtained for different machines

Table 2. Consistency test data for Ski-Doo TNT snowmobile

Snowmobile	Level Linear dBL_{in}	Average dBL_{in}	Standard deviation	Level weighted dBA	Average dBA	Standard deviation
1972 Models						
Machine L	97, 98, 99	98.0	1.0	90, 91, 92	91.0	1.0
Machine Q	97, 98, 99	98.0	1.0	90, 92, 92	91.3	1.2
Machine S	98, 101, 101	101.0	1.7	91, 92, 95	92.7	2.1
Average 1972 Models		98.7	1.5		91.7	1.5
1971 Models						
Machine T	94, 97	95.5	2.1	86, 88	87.3	1.1
Machine V	96, 99	97.5	2.1	87, 89	88.0	1.4
Average 1971 Models		96.5	2.1		87.6	1.1

of the same manufacture, model, and model year; in this case, Ski-Doo TNT, model years 1971 and 1972. The consistency of these values leads to the conclusion that identical models probably will have about the same sound levels.

Effects of Snow Conditions

One of the major objectives of the sound level measurements at 50 ft was to determine if the winter test procedure is valid regardless of differences in site parameters, such as snow type, small drifts of snow in the area, etc. Table 3 shows the range of conditions investigated, using the 1968 Moto-Ski 500. All data except first run results were obtained on the same test course. The total scatter in the data for this set of runs is no more than 2-1/2 dB. In addition to the data shown in table 3, field checks were made in two open fields and a racetrack, under a variety of snow conditions, with similar results.

Table 3. Effects of varying snow conditions

Condition	Average 50-ft level	Standard deviation
	dBA	
Old powder, well-packed	95	1.7
Identical snow conditions to above	$94\frac{1}{2}$	0.5
Very slushy wet snow, surrounding banks frozen hard	$93\frac{1}{2}$	1.0
Wet slushy snow, partly refrozen	93	0.7
4 in. new powder on hard base	93	0.6
6 in. new powder, very dry, very fast snow	95	1.0
2 in. new powder, dry and fast	$92\frac{1}{2}$	1.2

Analysis of Noise Source

The peak energy for virtually all snowmobiles tested was concentrated between the frequencies of 100 and 200 Hz, with a secondary peak in the vicinity of 1,000 to 2,000 Hz. The 1/3-octave band spectra obtained for the tests are shown in appendix 1. All but one graph gives the average spectrum obtained from at least two runs on each snowmobile; in most cases, three or four runs have been used to develop the data. Where more than one identical snowmobile model was tested, the graphs show the average spectrum for all of these machines.

All of the machines tested had two-stroke engines, the majority had twin cylinders. A primary firing frequency of 200 Hz would correspond to about 6,000 rpm. Thus, the peaks would seem to indicate that, although all the machines tested (with the exception of the Sno-Jet) were equipped with factory-installed mufflers, the largest percentage of sound energy escaping the snowmobile, and appearing as noise at 50 ft, comes from the exhaust system. Part of the primary peaks may be caused by intake noise.

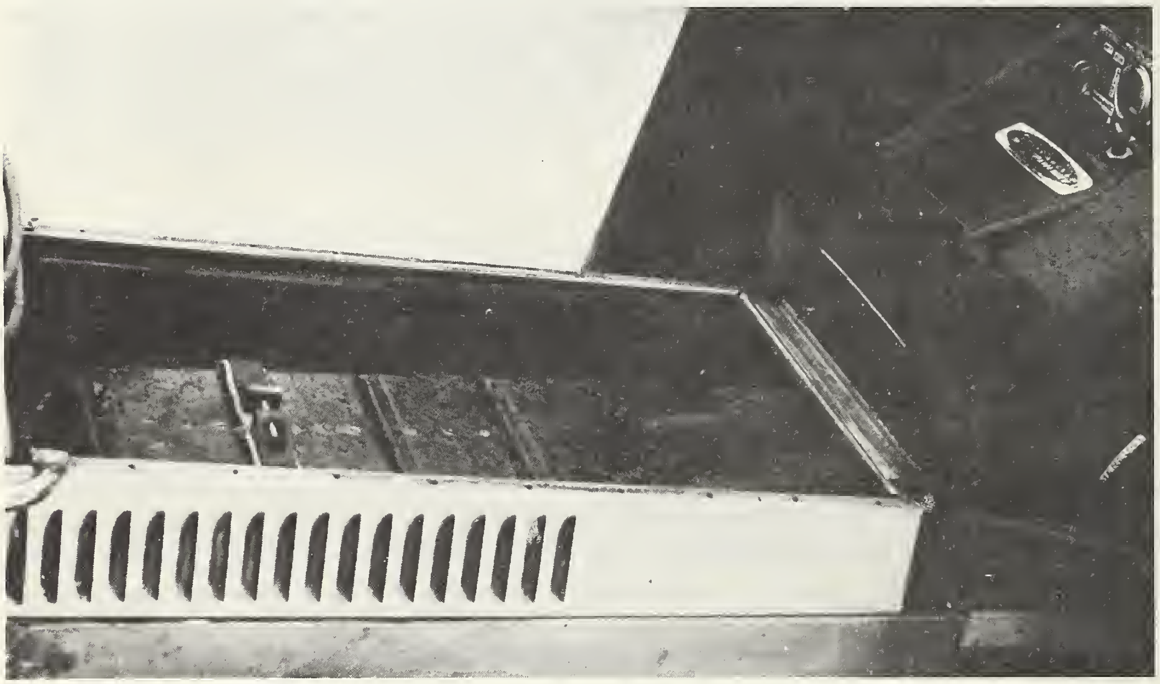


Figure 9. Mercury 250E muffler compartment with small muffler.

The secondary peaks in the 1,000 to 2,000 Hz frequency range averaged about 10 dB below the primary peaks, and are probably caused by mechanical noise radiated directly from the engine.

The noise of tracks and mechanical transmission would be expected to be in the lower frequency range. However, most of the snowmobiles tested showed little noise below 100 Hz. This probably indicates that the transmission and track noise for the machines tested are not significant when compared with exhaust and intake noise and engine noise radiation. The National Research Council of Canada report on snowmobile noise makes no mention of track noise (12). However, track noise will certainly become more significant if the intake, exhaust, and mechanical noises are reduced.

More effective mufflers would certainly reduce the overall noise level for most of the snowmobiles tested. Although it has been stated by representatives of the snowmobile industry that it would be difficult to fit larger mufflers to most machines, figure 9 shows that in at least one case this is not a valid argument. The picture

shows the muffler compartment located under the seat on a Mercury 250E. Note that a muffler of at least four times the volume of that presently installed could easily be placed in the existing muffler compartment. In fact, some 1972 and 1973 models produced by several manufacturers, including Mercury, are equipped with mufflers that reduce exhaust noise to a point where it is no longer the most significant contributor to overall machine noise.

Figure 10. Engine compartment of popular snowmobile with engine exposed.

Figures 10 and 11 show two popular snowmobiles. Neither indicates that thought has been given to shielding noise radiation from the engine. Figure 12 shows a popular snowmobile for which the engine is completely surrounded. It may be

Figure 11. Engine compartment of another popular snowmobile with engine exposed.

possible to engineer sound absorbing material into these shrouds. Lined ducts could be provided for cooling, and carburetor air or liquid cooling could be employed. In fact, just such treatment has been carried out on an experimental basis by the

Figure 12. Mercury 250E engine compartment with engine covered.

National Research Council of Canada (12). Their modified cowl provided an attenuation of 6 dBA on a well-muffled snowmobile. Although it is not the intent of this study to present detailed suggestions for the reduction of the noise levels from snowmobiles, it should be obvious that snowmobiles are considerably noisier than necessary from both an economic and engineering point of view. It has been reported that the Canadian Government has embarked upon an extensive program of research and development to produce quieter snowmobiles.

Discussion

The amount of general environmental pollution caused by snowmobile noise has been the subject of much attention. This report does not deal with setting of standards for forest areas, nor does it attempt to quantify the annoyance or disturbance caused by snowmobile noise. Annoyance has been treated at some length in Reference 5. A snowmobile producing 92 dBA (at 50 ft) would be detectable at approximately 11,000 ft with normal forest conditions. Likewise, an 83 dBA snowmobile would be detectable at 6,200 ft, and, if the level of the snowmobile were further reduced to 73 dBA at 50 ft, it would be detectable at only up to 2,800 ft. The calculations used to determine this distance are based on a method developed by Fidel, Pearsons and Bennett of Bolt, Beranek & Newman (17). The calculations and assumptions used are shown as appendix 2. It must be emphasized that this is only an estimate and that the distance would be somewhat less if noise propagation were upwind, or if snow cover were extremely heavy and considerable snow remained on the trees, or if mountains were located between the snowmobile and the receiver. These

Figure 13. Slushy course conditions.

calculations assume a background spectrum and level similar to that measured in a wild area in California (8). This was equivalent to approximately 45 dBA. Winter background levels as low as 11 dBA have been measured near Lolo Pass, Montana, a popular snowmobiling area. Under conditions of these lower backgrounds, or if there were downwind propagation, snowmobile detectability at distances considerably greater than 11,000 ft could be expected.

The range of test conditions encountered during this study probably approximates the extreme range that would be encountered in normal practice. Figures 1, 13, and 14

Figure 14. Powder snow course condition.

show three of the site conditions investigated. The test results indicate that the winter test procedure was valid for the various conditions encountered. It follows that this method could be used at any flat measuring location with validity, as long as the parameters set forth in figure 2 are observed.

At-Ear Sound Level Measurements

The at-ear sound level measurements were obtained on four machines; the Moto-Ski 500, a Moto-Ski Zephyr, an Arctic Cat Panther, and a Ski-Doo Alpine 399ER. The snowmobile passenger held the microphone of the sound level meter at the operator's left and right ears, and at his own, while the snowmobile was accelerated from a stop to maximum speed. No recordings or spectral analyses were made of the at-ear sound level data, only A-weighted and linear levels were obtained. The tests were run in a large open field in a variety of snow conditions; the difference in snow conditions did not make any difference in the levels observed. Whether the response of the precision sound level meter used was set at "fast", "slow", or "hold" (which "catches" the needle at its loudest swing, excluding extraneous bumps), no difference was noted in maximum levels obtained. The microphone location was varied throughout the range of positions at which the operator's and passengers' ears could be expected. These variations accounted for less than 2 dBA difference in the results. Table 4 shows these results. At engine idle the sound level of all the machines dropped to from 83 to 90 dBA as measured at the operator's ear.

Table 4. At-ear snowmobile sound levels

Model	Operator's ear				Passenger's ear			
	Left		Right		Left		Right	
	dBL_{in}	dBA	dBL_{in}	dBA	dBL_{in}	dBA	dBL_{in}	dBA
Moto-Ski 500	121	113	121	115	116	105	116	106
Moto-Ski Zephyr	121	117	119	115	---	---	---	---
Arctic Cat Panther	109	103	108	103	---	---	---	---
Ski-Doo Alpine 399ER	108	103	108	105	---	---	---	---

Some question may arise as to the accuracy of this data because of the wind noise generated at the operator's ear, caused by the forward motion of the snowmobile. Wind noise generated by the windscreen used is only 80 dB at speeds used for the test (ref. 3). Therefore, wind noise is not a significant contributor to the overall reading obtained.

It is unfortunate that it was not possible to measure the at-ear sound level using a greater number of snowmobiles. It is recommended that further work be performed in this area.

Dosage or Cumulative Exposure Measurements

Dosage, or the total cumulative sound energy to which an operator is exposed, was measured in these tests. Figure 15 presents the results of the cumulative exposure tests. The ordinate is sound level in dBA. The obscissa is the cumulative percent of the total time the operator's ear spent at a given sound level. In other words, referring to the figure, we can see that 96 percent of the time the operator was subject to greater than 85 dB, 85 percent more than 90 dB, 60 percent more than 95 dB, and so on, while 2 percent of the time was spent at levels greater than 110 dBA. The exposure time shown appears to reflect a normal distribution.

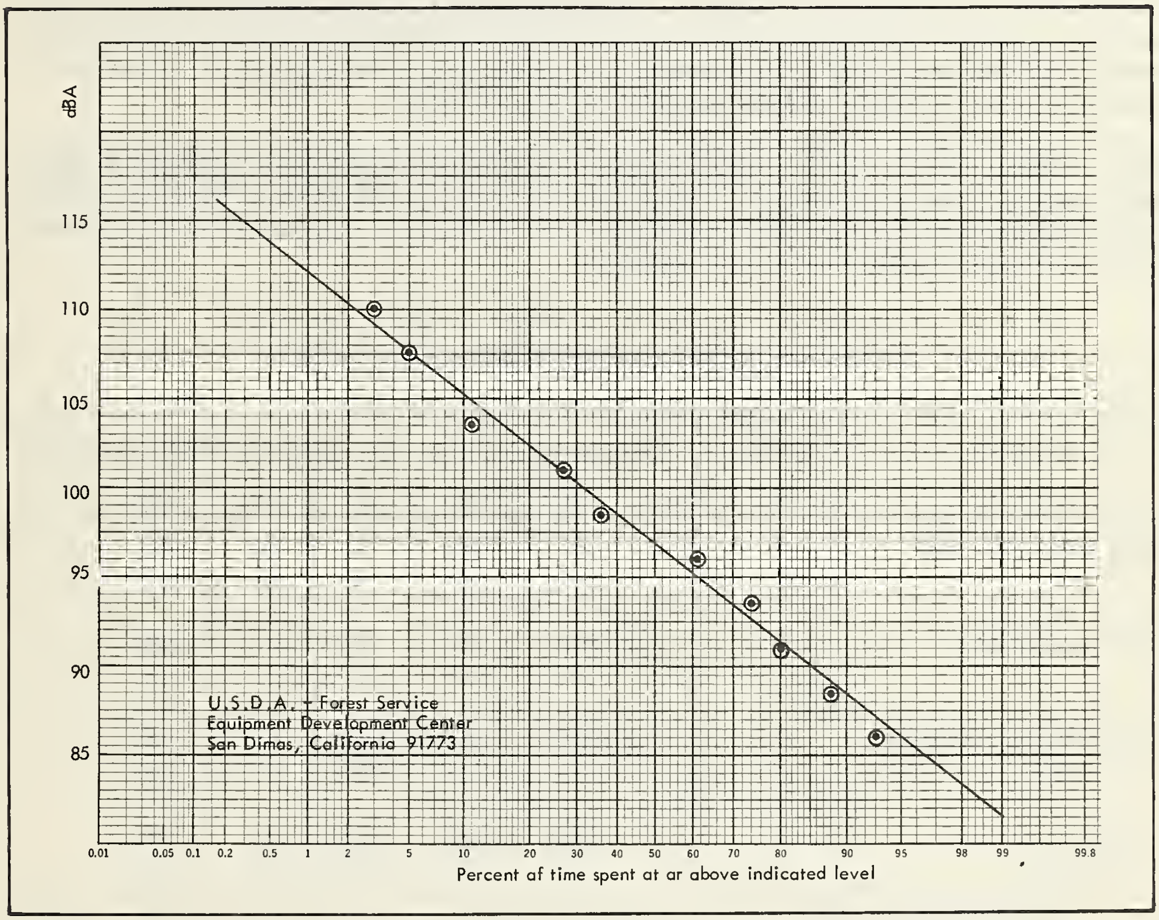


Figure 15. Cumulative exposure time as a function of level, two snowmobile operators.

These data represent the average exposure for two Forest Service employees operating four snowmobiles in what was considered to be a typical recreational pattern. Each had some recreational experience with snowmobiles. It included "blasting

around" in an open field, as well as cross-country travel. Three separate locations were used. The proportional relationship between these two patterns was approximately 20 to 80 percent.

Although the total period of time was somewhat less than the normal snowmobile recreational operating period, the proportion of time spent in each "amplitude range" was felt to be representative of normal recreational operation.

The total exposure time commenced when the machine was started, and stopped when the machine had been returned to its parking place; that is, idle time and resting time on the trail, time spent digging out of snow drifts, etc., were included. Both of the operators showed at least 10 dB temporary threshold shift at at least one frequency tested after 1-hour sessions on the snowmobile.

The exposure cycle data were taken with the snowmobile operator using a variety of normally used riding positions; that is, kneeling on the seat, standing on the footboards, as well as sitting. No attempt was made to sort out the at-ear sound level exposure cycle for these various operator body positions.

Table 5 shows the machines used and also presents the levels as a function of right ear exposure time percentages. Table 5 shows that there is little difference in the levels experienced by the two operators. The data also indicate that location of travel and snow conditions are not important.

Table 5. Operator at-ear exposure durations

Snowmobile	Rider	Time spent at or above indicated dBA level (%)				
		10	25	50	75	90
1968 Moto-Ski 500	1	107	100	97	96	94
	2	110	103	97	91	87
1971 Raider 400	1	103	101	97	91	86
	2	103	100	97	91	86
1970 Ski-Doo Alpine 399ER	1	102	100	99	97	95
	2	105	103	100	96	90
1970 Arctic Cat Panther	1	102	100	98	94	88
	2	104	100	97	91	86

Despite large differences in maximum at-ear and 50-ft sound levels for the various snowmobiles tested (see tables 1 and 4), the levels at which the operator's ear spends 25 percent or more of its time are substantially the same for all snowmobiles tested. For about 10 percent of the time, however, the at-ear sound levels of the louder machines are significantly greater than those of the quieter ones. For instance, the Federal Occupational Safety and Health Act limits (4) are exceeded

by the Moto-Ski in 2.4 hr, whereas 3 to 5 hr of operation on the Raider are permissible. The other two snowmobile noise limits ranged between these two extremes.

Informal interviews with several operators were conducted to try to establish the amount of time the average snowmobile rider spends on his machine during a normal recreational day. The most common time mentioned was about 4 hr, although a 6-hr ride was not unusual. In addition to more extended periods on a weekend, many snowmobile owners "play" for an hour or two after work, if the weather permits.

Discussion

Considerable difference in the exposure pattern may exist between travel for official duty purposes and recreational snowmobile riding. Our observations indicate that official duty riding would be more severe than recreational riding because most travel is probably over fairly well prepared roads and trails, thus higher speeds and wider throttle openings would be appropriate.

Operator Temporary Threshold Shift Measurements

The operator temporary threshold shift (TTS) measurements were based on comparisons of the pre-exposure and post-exposure audiometric tests.

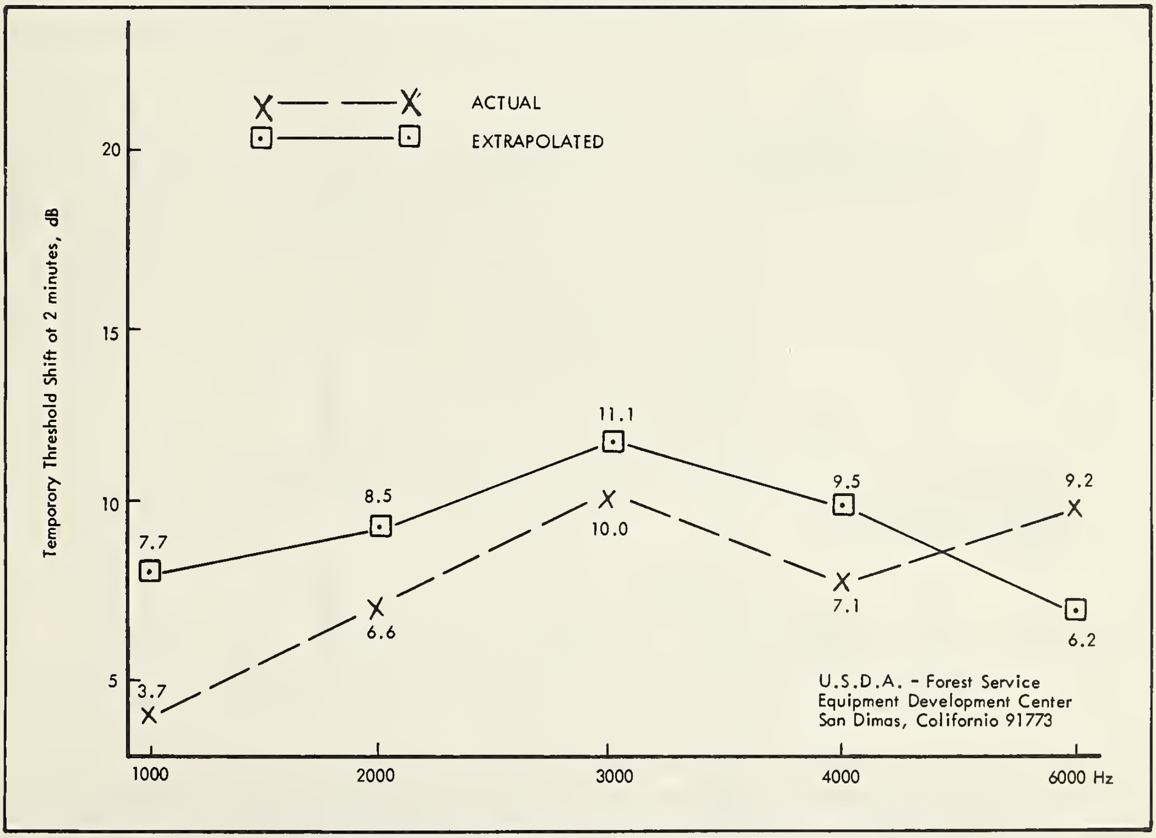


Figure 16. Actual vs. extrapolated temporary threshold shift at 2 min, with 30 min exposure.

In the volunteer group, the average post-exposure time at the beginning of threshold tests was 11 min. The amount of TTS at the onset of the post-exposure test was extrapolated back to TTS at 2 min (TTS_2) for comparison, using Ward's procedure (7). It is recognized that, strictly speaking, the TTS_2 can apply only to the beginning of the test, with the higher frequencies being tested at up to 3 min later. These measurements, then, underestimate the shift that would have been present had each frequency been tested within the 2-min period.

In the controlled group as many post-exposure audiograms as possible were taken at 2 min after exposure, giving actual TTS_2. When post-exposure audiograms were taken at longer intervals after exposure, the technique mentioned above was used to obtain extrapolated TTS_2. Serial threshold data obtained on six subjects supported the reliability of both the audiometer and the technique.

Temporary Threshold Shift Comparisons

Figure 16 shows actual versus extrapolated TTS_2 on subjects from both groups who had 30 min of exposure on a variety of snowmobiles under typical operating conditions. The 2-min values for four of the five frequencies fall within plus or minus 2 dB, with a maximum deviation of 3 dB. It would appear that, at least for short, carefully measured post-exposure intervals, extrapolation is an adequate means of estimating the temporary threshold shift at 2 min under field conditions.

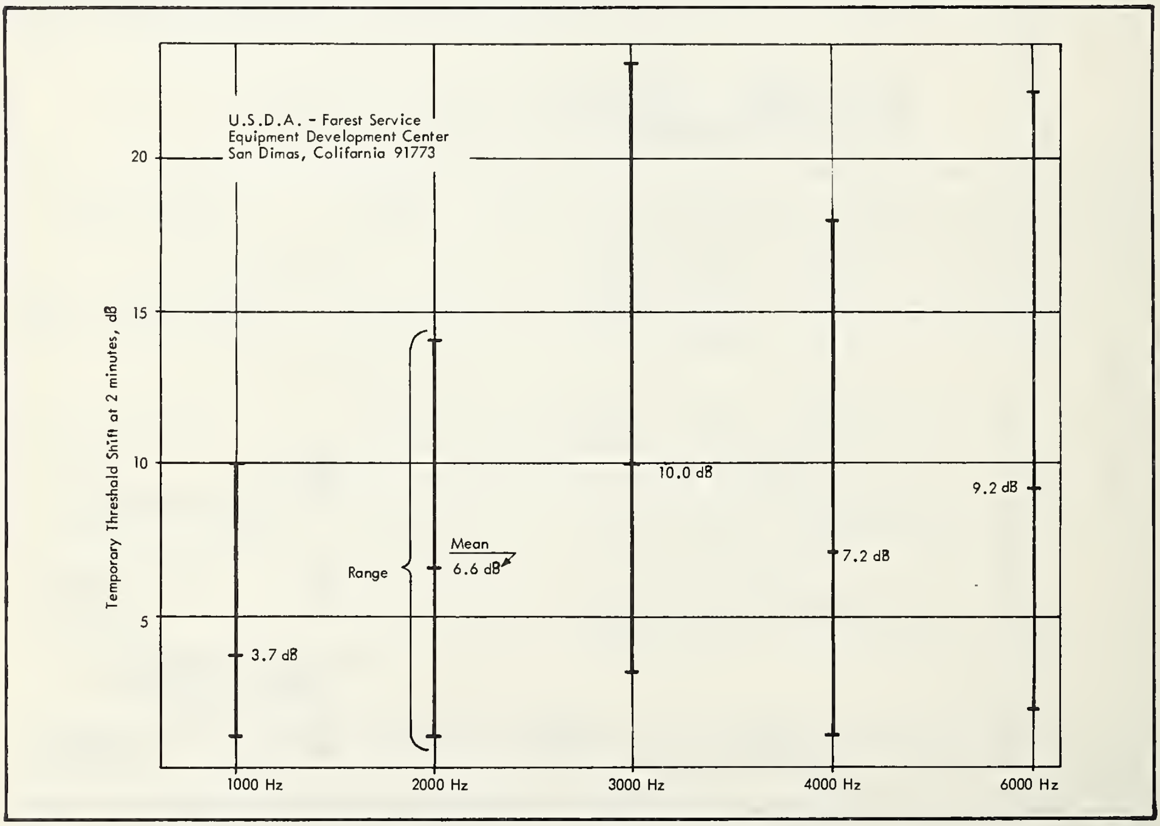


Figure 17. Temporary threshold shift at 2 min, means and range, controlled group.

Figure 17 shows the means and range of TTS_2 in 16 subjects, the controlled group, after 30 min on a snowmobile with noise levels at the ear ranging from 90 to 114 dBA. It will be noted that the mean amount of threshold shift at 2 min is an unsatisfactory measure since several of the subjects show important amounts of shift at 3, 4, and 6 kHz, especially considering the short exposure time. The actual amount of temporary threshold shift may have been greater in some frequencies at 3, 4, or 6 kHz, except that several of the subjects exhibited a pre-existing permanent hearing loss at those frequencies.

Figure 18 contrasts the average levels of temporary threshold shift at 2 min with actual levels shown for the controlled group and extrapolated levels for the volunteer group. Average exposure time was 70 min longer for the volunteer group than for the experimental group. The average of 100 min on a machine can be considered a more realistic estimate of typical recreational exposure time than the controlled group's 30 min. The greater amount of temporary threshold shift, particularly the growth at 1 kHz, cannot be ignored.

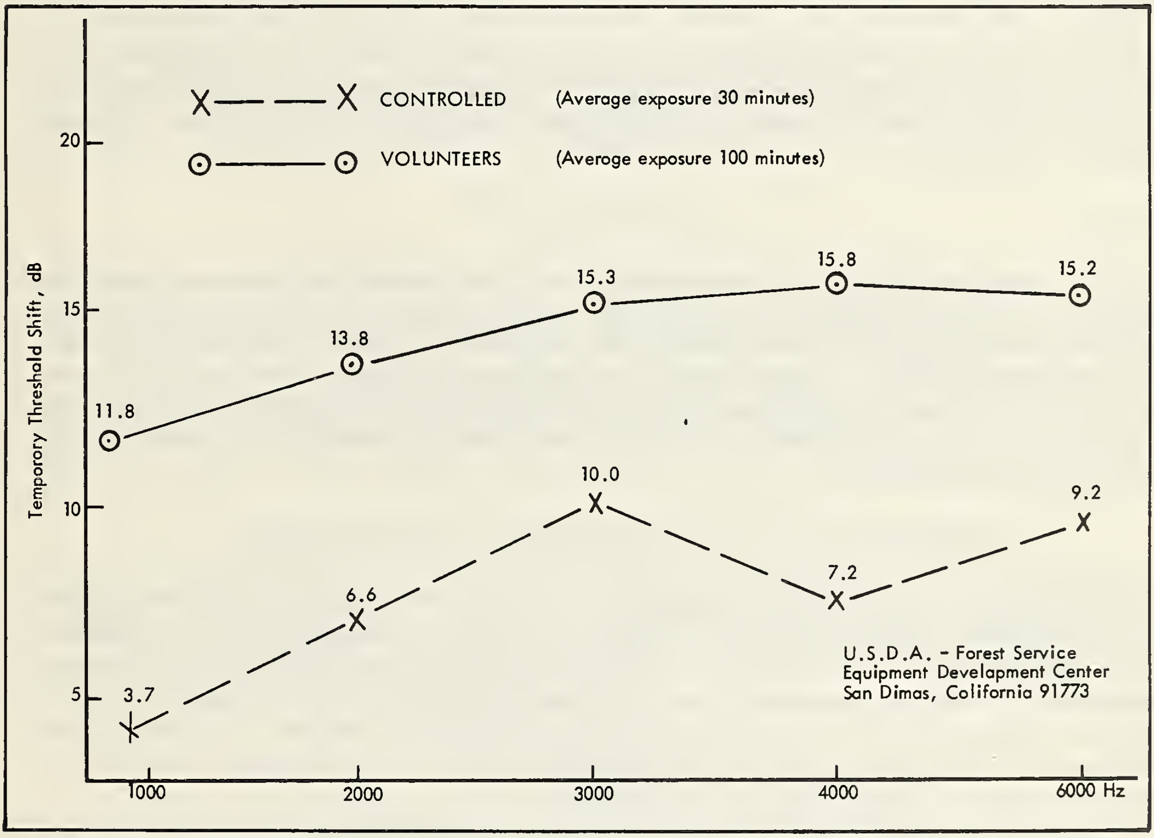


Figure 18. Controlled vs. volunteer groups, temporary threshold shift at 2 min.

Correlations between the predominant frequencies in the spectrum of the snowmobile's noise and the frequencies of greatest temporary threshold shift were not made. But, preliminary inspection of the data suggests that maximum shift occurs at one-half to one octave above the prominent peaks in the noise, which is as expected. However, since the spectral distribution varied from one snowmobile to

another, there is no single frequency that consistently showed the greatest threshold shift in the riders tested.

From a preliminary analysis of the data two interesting phenomena were observed. For some subjects we noticed a reduction in the relative size of the excursion of post-exposure test in which other contexts is considered characteristic of recruitment or other cochlear insult; and in some cases we noticed an enhanced post-exposure threshold in the higher frequency adjacent to the one that showed a loss. This phenomenon was dubbed the "bedspring effect."

The temporary threshold shift at 2 min from noise exposure has been used to index the potential damage risk to hearing by Kryter and various working groups of CHABA (National Academy of Sciences, National Research Council, Committee on Hearing Bioacoustics and Biomechanics). Specifically, noise exposures that produce greater than 10 dB at less than 500 Hz, 15 dB at 500 to 2,000 Hz, and 20 dB at greater than 2,000 Hz, could result in hearing changes that pose a handicap to speech reception (9, 10).

Figures 17 and 18 show that some of the controlled group suffered a TTS significantly in excess of these criteria, and the <u>average</u> TTS experienced by the volunteer group in the 3, 4, and 6 kHz frequency bands approaches these criteria with an average exposure of 100 min.

Discussion

Based on collected data, it is impossible to conclude categorically that snowmobile operation will cause operator hearing loss. However, the limited amount of data available certainly indicates that a significant portion of the snowmobiling population will be exposed to sound levels that could cause permanent damage to their hearing. This contention is supported by work done by Poynor and Bess and presented in a paper at the Annual American Speech and Hearing Association Convention in New York for 1970 (15).

A PROPOSAL FOR A SNOWMOBILE NOISE STANDARD

The foregoing data indicate that enough is now known to establish a noise standard for snowmobiles used on National Forest lands. Such a standard must be based on knowledge of what is achievable in terms of quieting snowmobiles, rather than on knowledge of what is acceptable to forest users; thus, it is open to some criticism. However, the demand for a standard has been clearly demonstrated. Several representatives of the Forests and the Regions have asked the Equipment Development Center for help in formulating such a standard.

Several states, as well as the Canadian Government, now impose noise regulations upon snowmobiles. Work carried out by the National Research Council of Canada has demonstrated that snowmobiles can be made that generate no more than 75 dBA at 50 ft (12), and more recent work by Cowl Industries in Canada has resulted in even lower levels. Almost all snowmobiles manufactured after January 1, 1973, by members of the International Snowmobile Industries Association, which represents 90 percent of this continent's snowmobile production, will generate no more than

82 dBA, measured according to SAE J192 procedures. Manufacturers are continually working to silence their snowmobiles, and one manufacturer, Bombardier (who manufacturers Ski-Doo) has publicly demonstrated a 1974 prototype that was measured at 78 dBA at 50 ft. At this level, the noise of track and ski interaction with the snow surface becomes significant. Thus it will prove very difficult to silence snowmobiles much below this level, say 75 dBA, without radically altering their basic design.

Although one manufacturer claims to sell a 73 dBA snowmobile, other manufacturers who have purchased and tested this model state that its 50-ft level is closer to 78 dBA. Also, it is a large, heavy "Luxury" snowmobile, and thus degraded less by weight increases caused by noise suppression equipment than the lighter, cheaper, and far more popular small machines.

To encourage continued noise reduction efforts on the part of manufacturers, an "ultimate" level should be specified. The noise standard proposed below demands an approximate reduction of snowmobile noise of 1-1/3 dB per year. A 50-ft level of 73 dB would reduce the auditory detection distance to about 1/2 mile under average conditions. This would seem to be a good target that follows the "schedule" established in the proposed standard. Recognizing that each incremental reduction in noise is more technically difficult than the last, an ultimate level of 73 dBA at 50 ft should not be required before the year 1980.

Older Machines

The foregoing comments pertain only to machines manufactured after January 1972. Older machines could be louder. If the owners have removed the mufflers, they will be <u>much</u> louder. Data for the Snow-jet tested, table 1, clearly demonstrate this. It is impractical to retrofit snowmobiles with equipment to silence them beyond a certain point, usually about 85 to 90 dBA at 50 ft. Below this level, an exhaust muffler alone is not sufficient, and silencing of intake, mechanical, and track noise becomes necessary. This is nearly impossible to do economically on an existing machine.

However, all machines, with the exception of special racers, sold in the last 6 years have been equipped with at least some form of exhaust muffler. The average life of snowmobiles is estimated at 3 to 5 years. Thus, it seems logical to insist that any snowmobile used on National Forest lands be equipped with a muffler at least equivalent to the manufacturer's original equipment.

Proposed Standard

The proposed standard deals only with environmental noise and does not adequately protect operator hearing. Since it has not been shown to be feasible to lower operator's ear noise to a safe level, hearing protection for snowmobile operators is recommended.

1. All snowmobiles operated on National Forest lands must be equipped at all times with an exhaust muffler, equivalent in performance to the manufacturer's original equipment. When a snowmobile has been sold without an exhaust muffler,

silencing equipment must be installed, including but not limited to an exhaust muffler, so that the total sound level measured by the Forest Service winter test method does not exceed 92 dBA.

2. All snowmobiles, operated on National Forest lands, that were sold after June 1, 1972, shall not produce a sound level greater than 82 dBA, when measured according to the Forest Service Snowmobile Winter Test Procedure.

3. All snowmobiles, operated on National Forest lands, that are sold new after June 1, 1975, shall not produce a sound level greater than 78 dBA, when measured according to the Forest Service Snowmobile Winter Test Procedure.

4. All snowmobiles, operated on National Forest lands, that are sold new after June 1, 1980, shall not produce a sound level greater than 73 dBA, when measured according to the Forest Service Snowmobile Winter Test Procedure.

Nearly all evidence available at this time indicates that sound level measurements made at 50 ft using the FSSWTP will be nearly equal to levels obtained using the SAE J192 procedure. This is particularly true if measurements are made in fresh snow, or at higher elevations. Thus, the winter test method can be validly used to determine whether or not a snowmobile meets the foregoing proposed standard. However, an additional tolerance of 3 dBA should be allowed because of uncertainties in course parameters, measuring equipment, etc.

CONCLUSIONS

Based on the test conducted and data analysis, the following conclusions are summarized:

1. For average recreational riding, the Occupational Safety and Health Act noise limitations are exceeded after approximately 3 hr of snowmobile operation. Under an official duty travel situation, this time likely would be shorter.

2. The noise of a typical snowmobile presently in use will probably be detectable in the typical winter forest within a distance of about $1\frac{1}{2}$ miles from the snowmobile under normal conditions. Under quiet background conditions, this distance could easily be much greater.

3. Significant temporary threshold shift was seen in nearly all snowmobile operators tested after the use of snowmobiles for periods as short as 1/2 hr. The degree of permanent damage caused by snowmobile noise is not known at this time, but it can be stated that continued exposure to present snowmobile noise levels will likely cause permanent damage to an individual's hearing.

4. The Forest Service Snowmobile Winter Test Procedure developed during the course of this project can be used successfully to measure the amount of noise produced by a snowmobile.

5. Snowmobiles are considerably noisier than economic or technical reasons justify.

RECOMMENDATIONS

As a result of this study, it is recommended that:

1. The following noise standards for snowmobile be adopted. All measurements under the standard to be made using FSSWTP.

All snowmobiles except as below	92 dBA
Snowmobiles first sold after June 1, 1972	82 dBA
Snowmobiles first sold after June 1, 1975	78 dBA
Snowmobiles first sold after June 1, 1980	73 dBA

2. Forest Service employees who use snowmobiles in the course of their work should be cautioned as to the noise hazard of snowmobiles and required to wear hearing protection during snowmobile operation.

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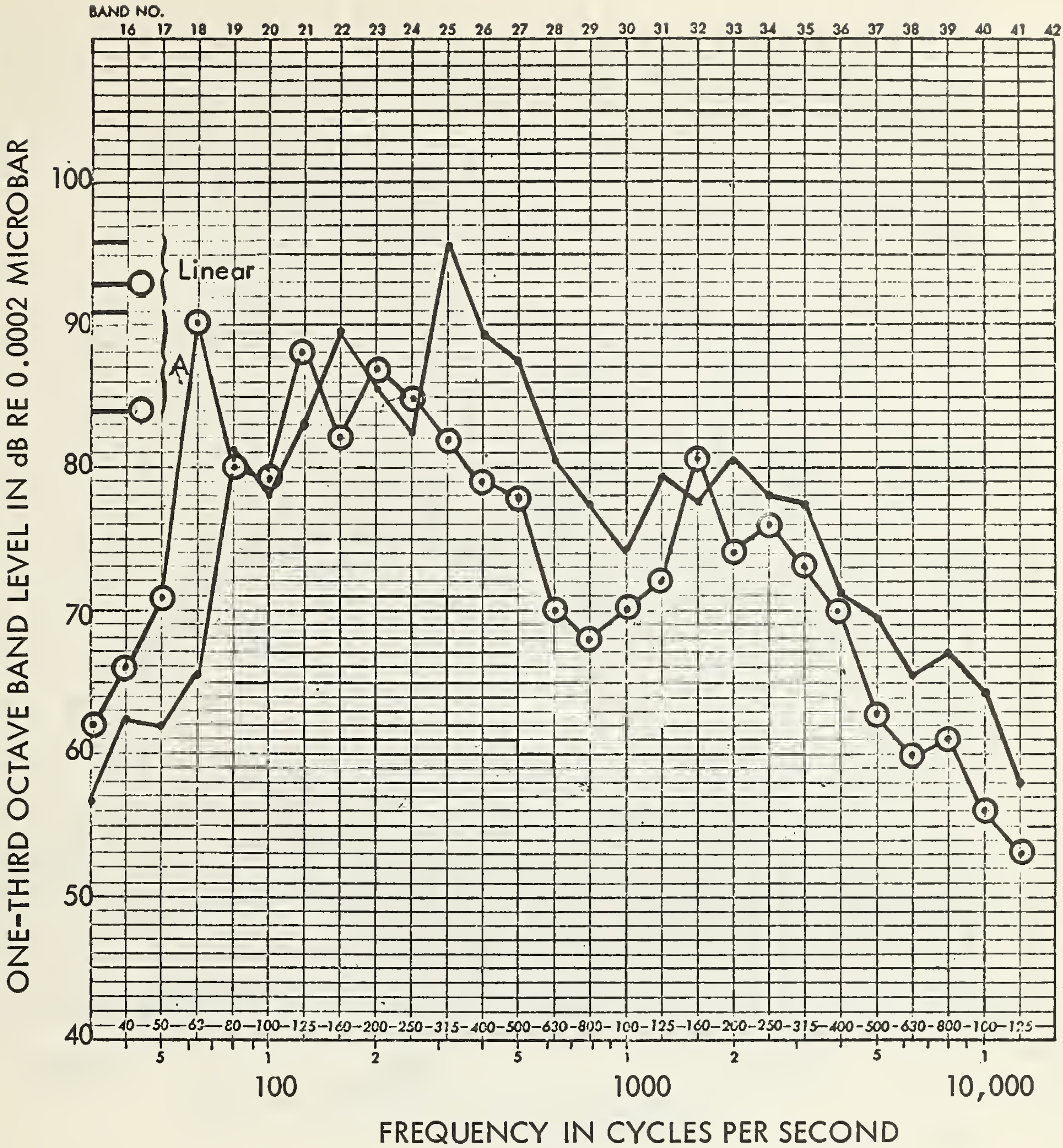
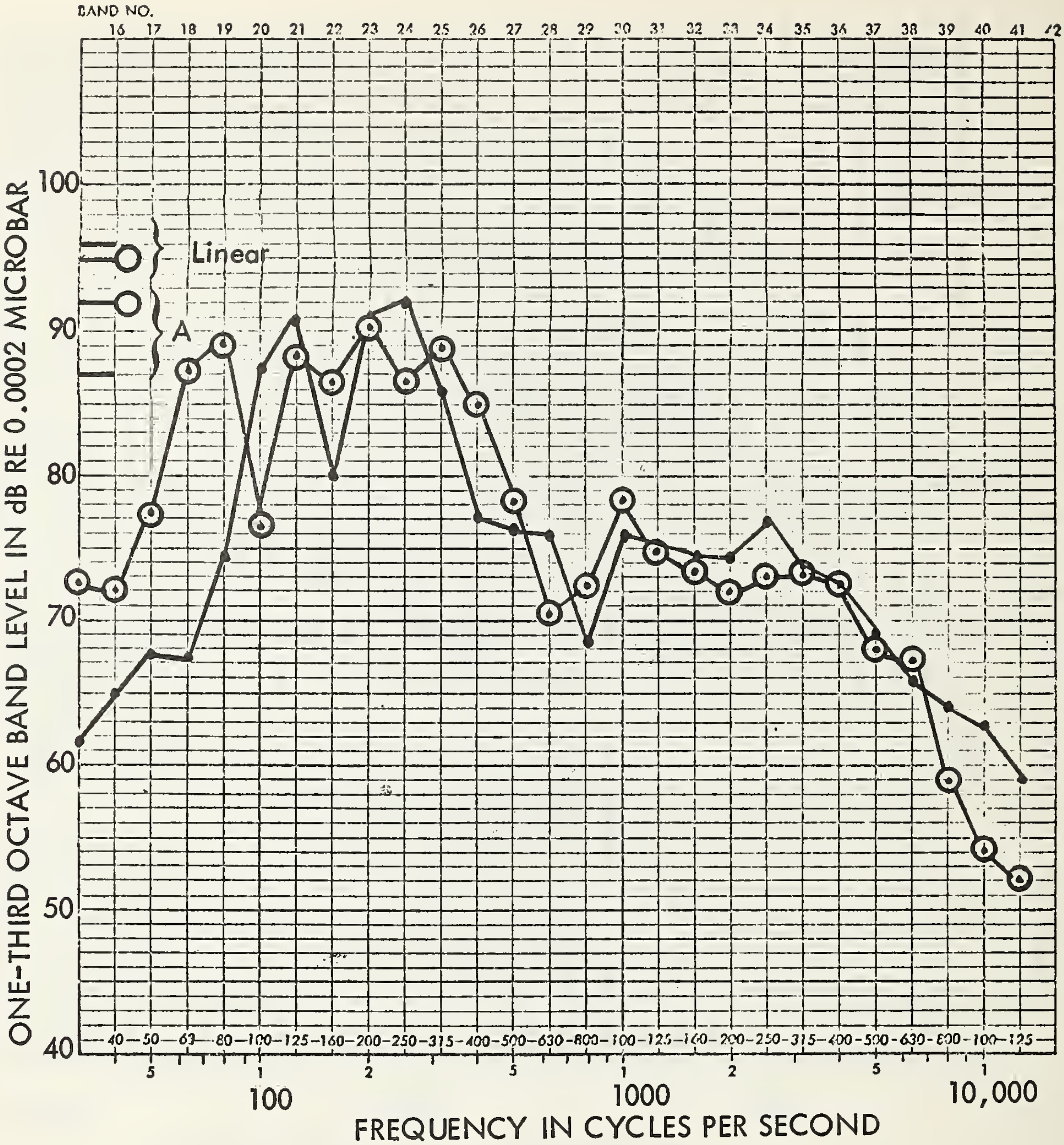
APPENDIX I

ONE-THIRD OCTAVE SPECTRA FOR TEST SNOWMOBILES



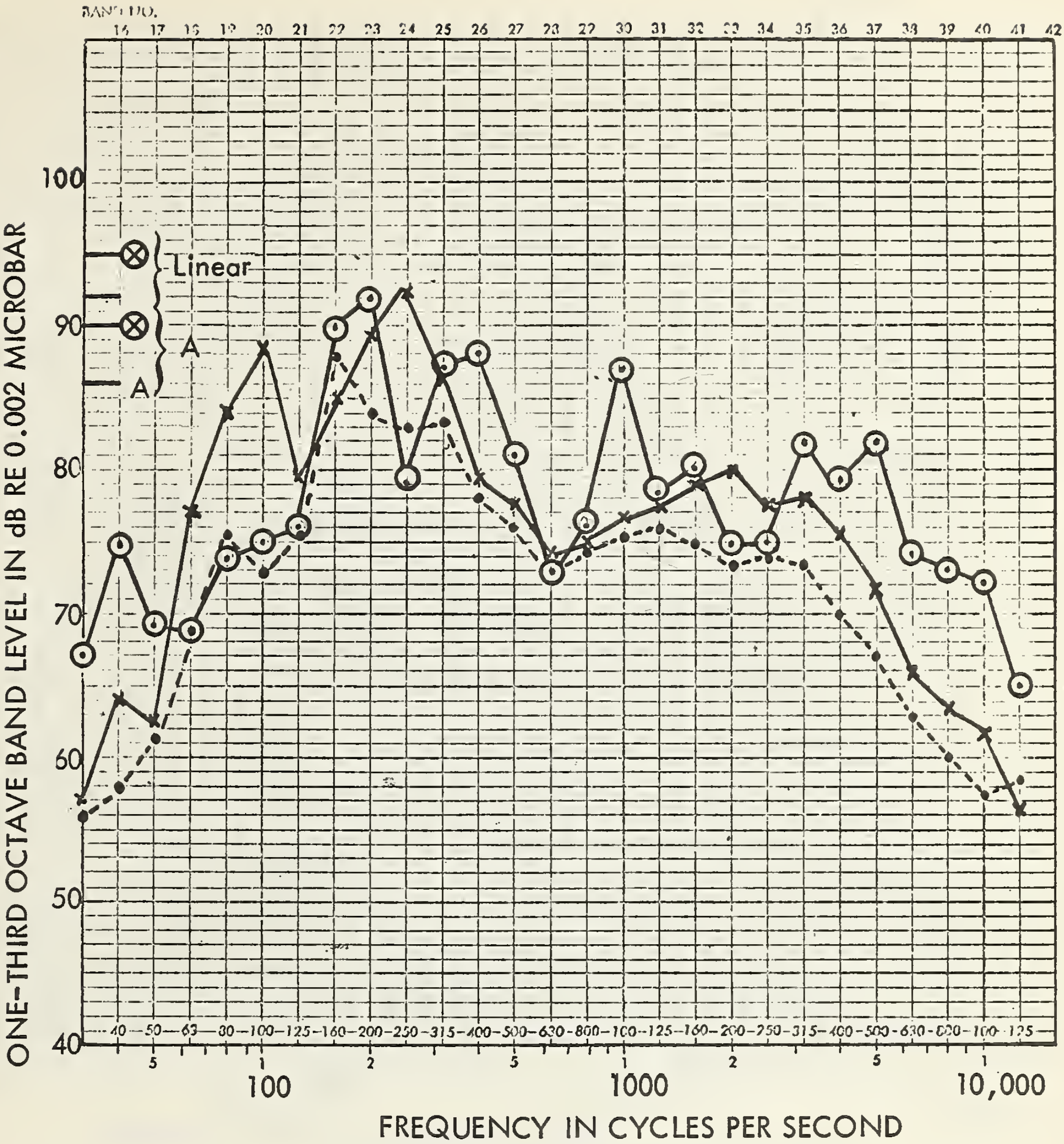
1968 Polaris Mustang
1 run

1971 Polaris TX
Average of 3 runs



—O—O— 1967 Evinrude Skeeter
Average of 2 runs

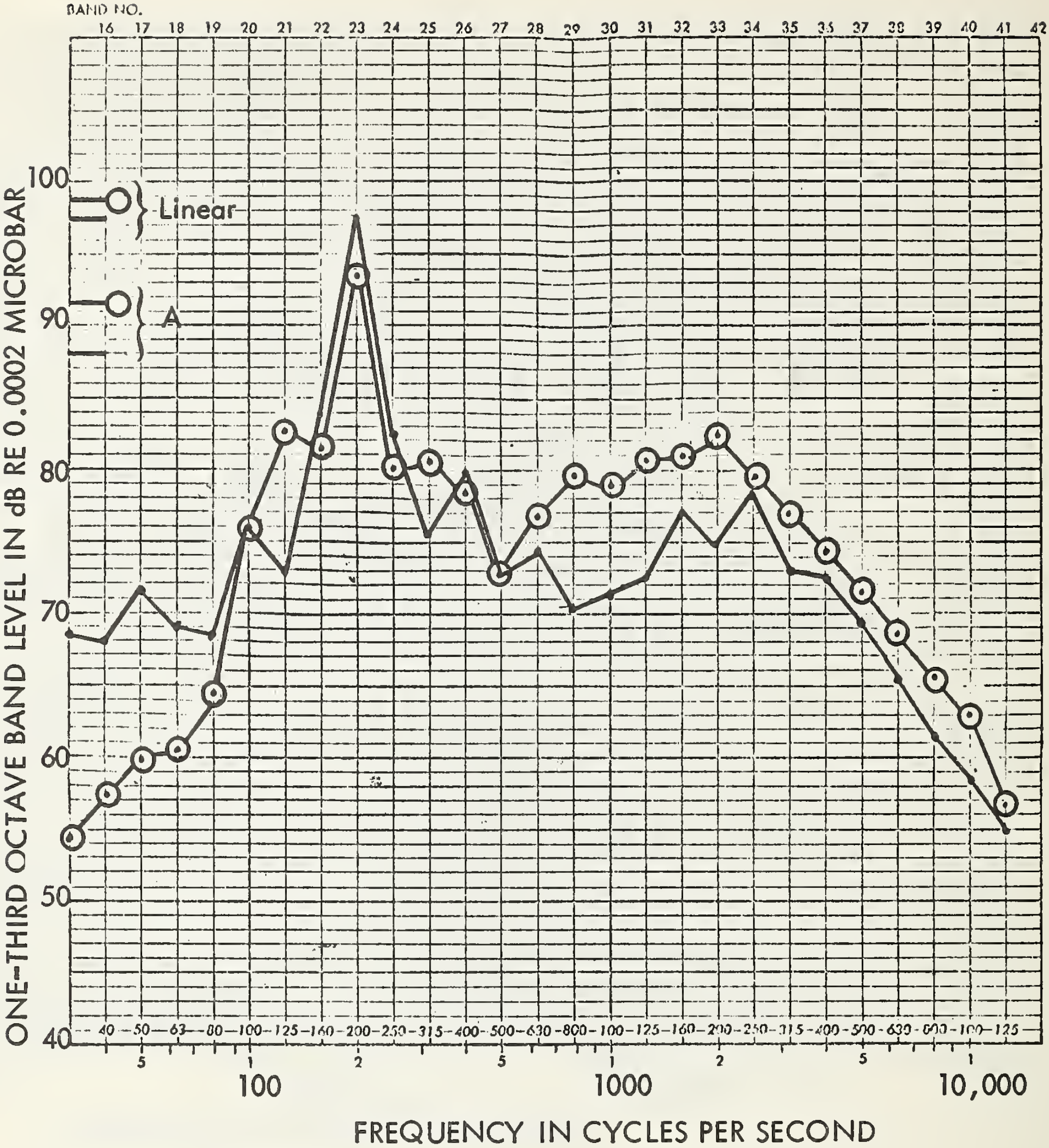
——— 1971 Evinrude Skeeter
Average of 2 runs



—O—O— 1968 Ski-Doo 300
One Run

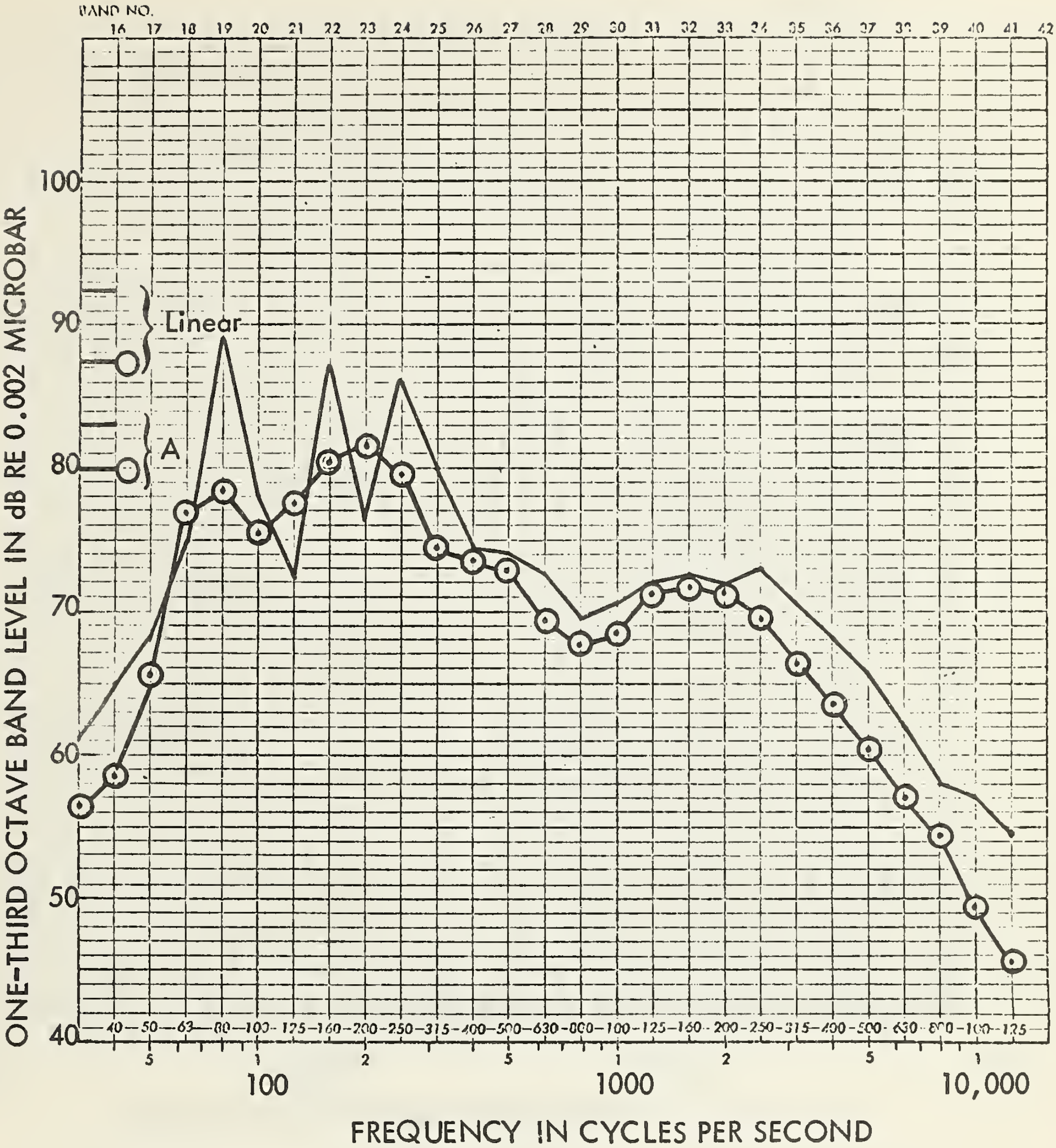
—×—×— Ski-Doo Olympique
Average of 3 runs

——— Ski-Doo Nordic 371
Average of 2 runs



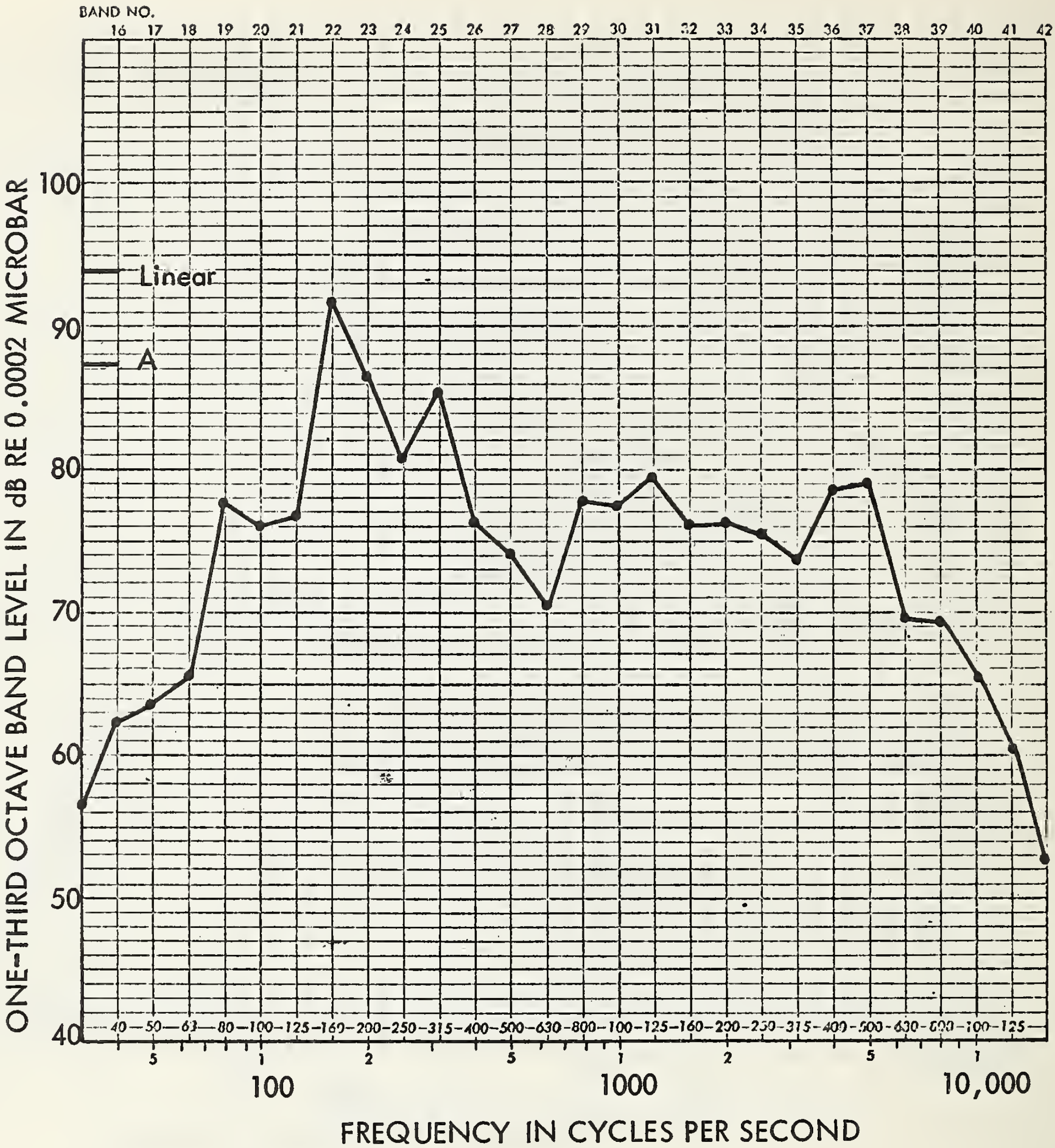
1972 Ski-Doo TNT
3 Machines, Average of 9 runs

1971 Ski-Doo TNT
Average of 2 runs

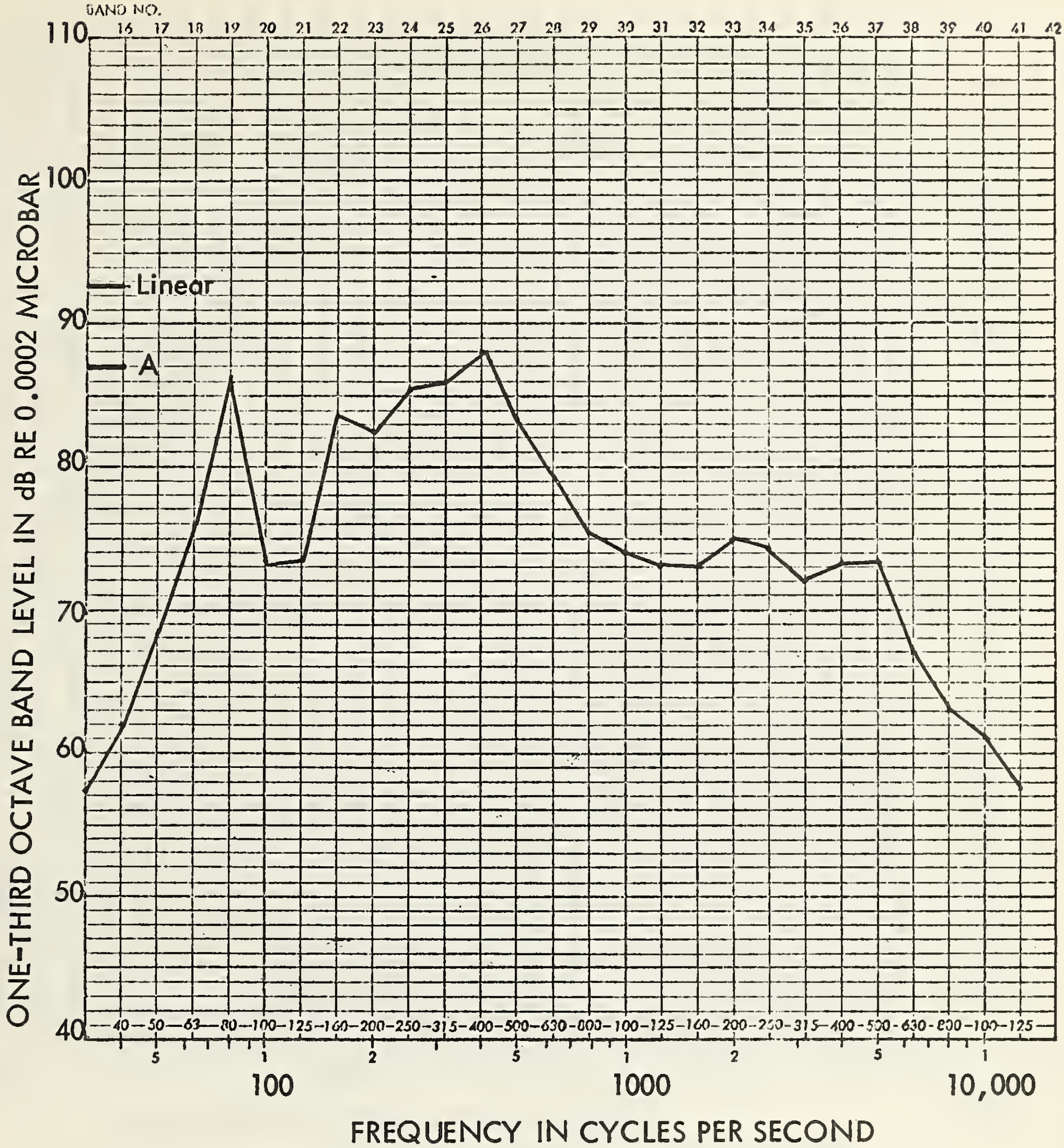


—O—O— 1972 Ski-Doo Elan
2 machines, Average of 6 runs

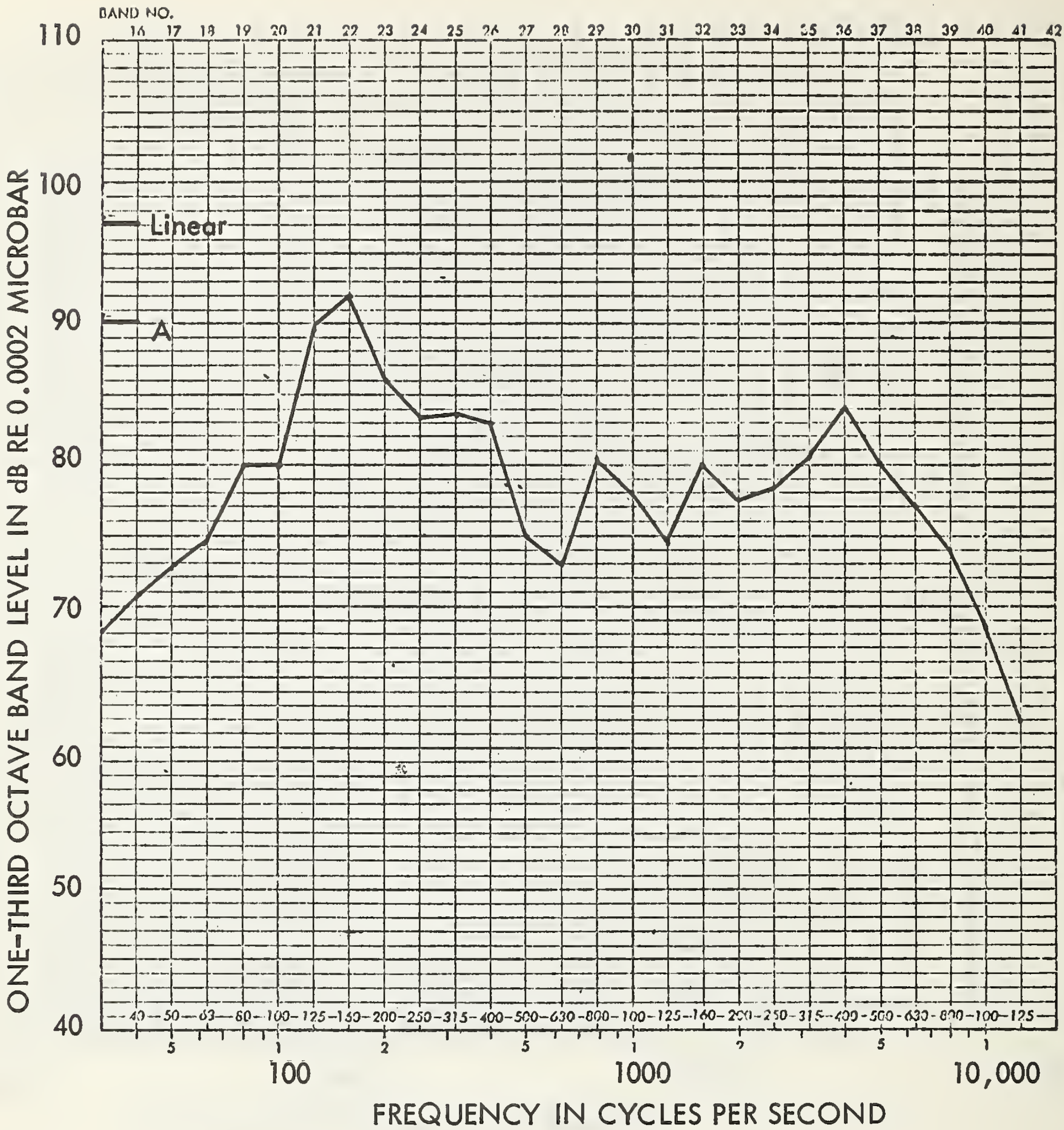
———— 1971 Ski-Doo Elan
Average of 2 runs



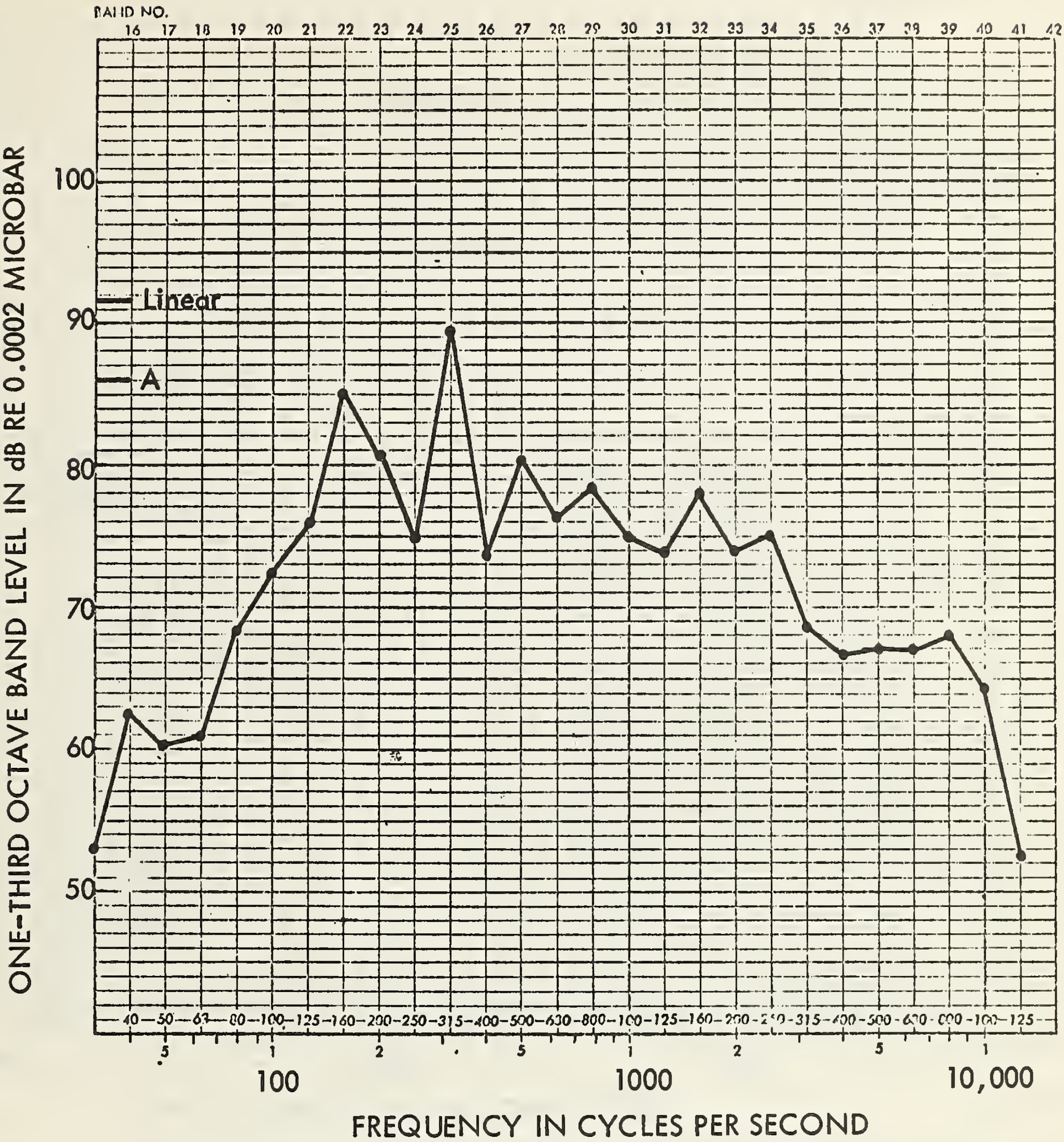
1968 Moto-Ski 500
Average of 14 runs



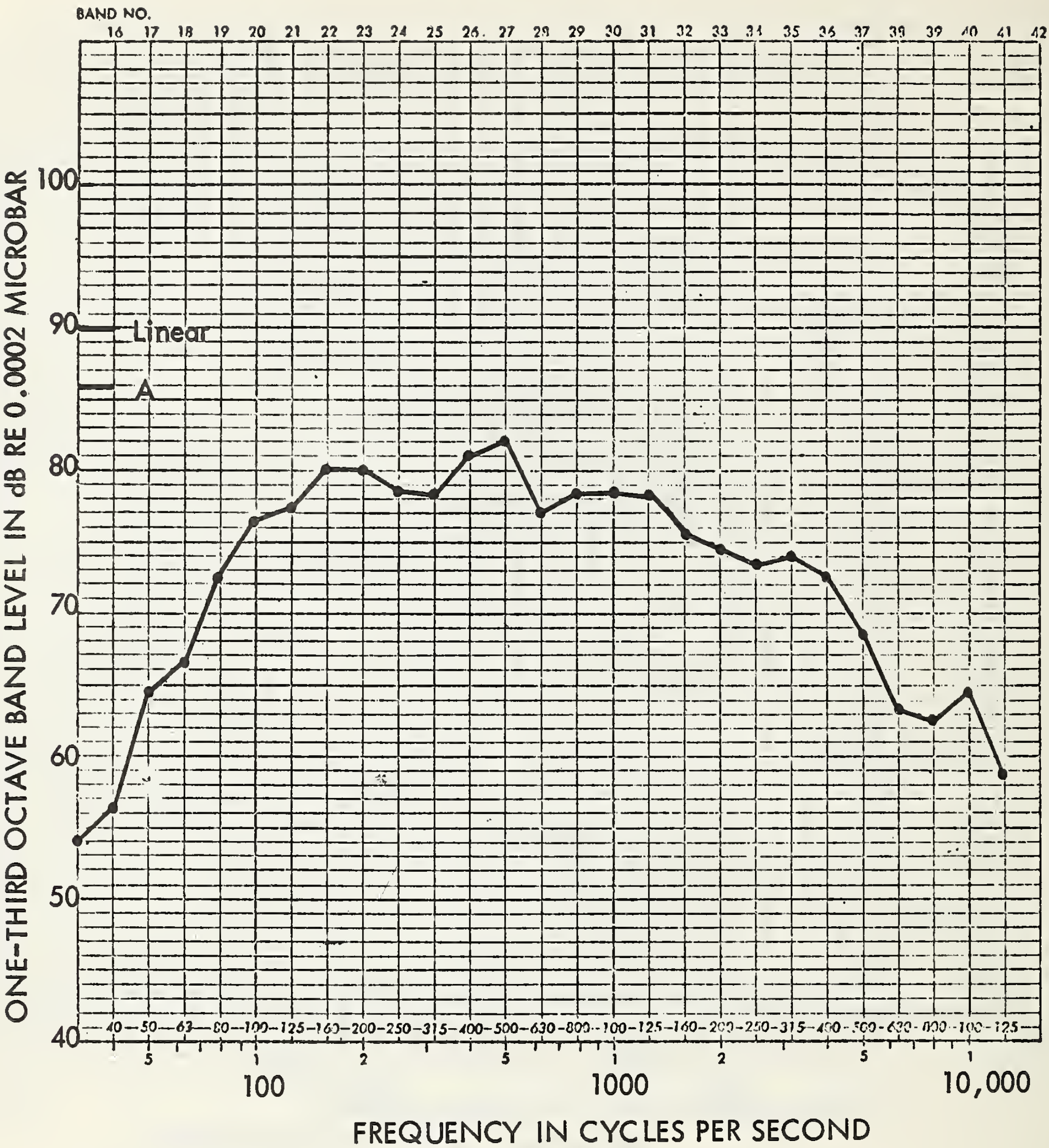
1969 Moto-Ski Zephyr
Average of 3 runs



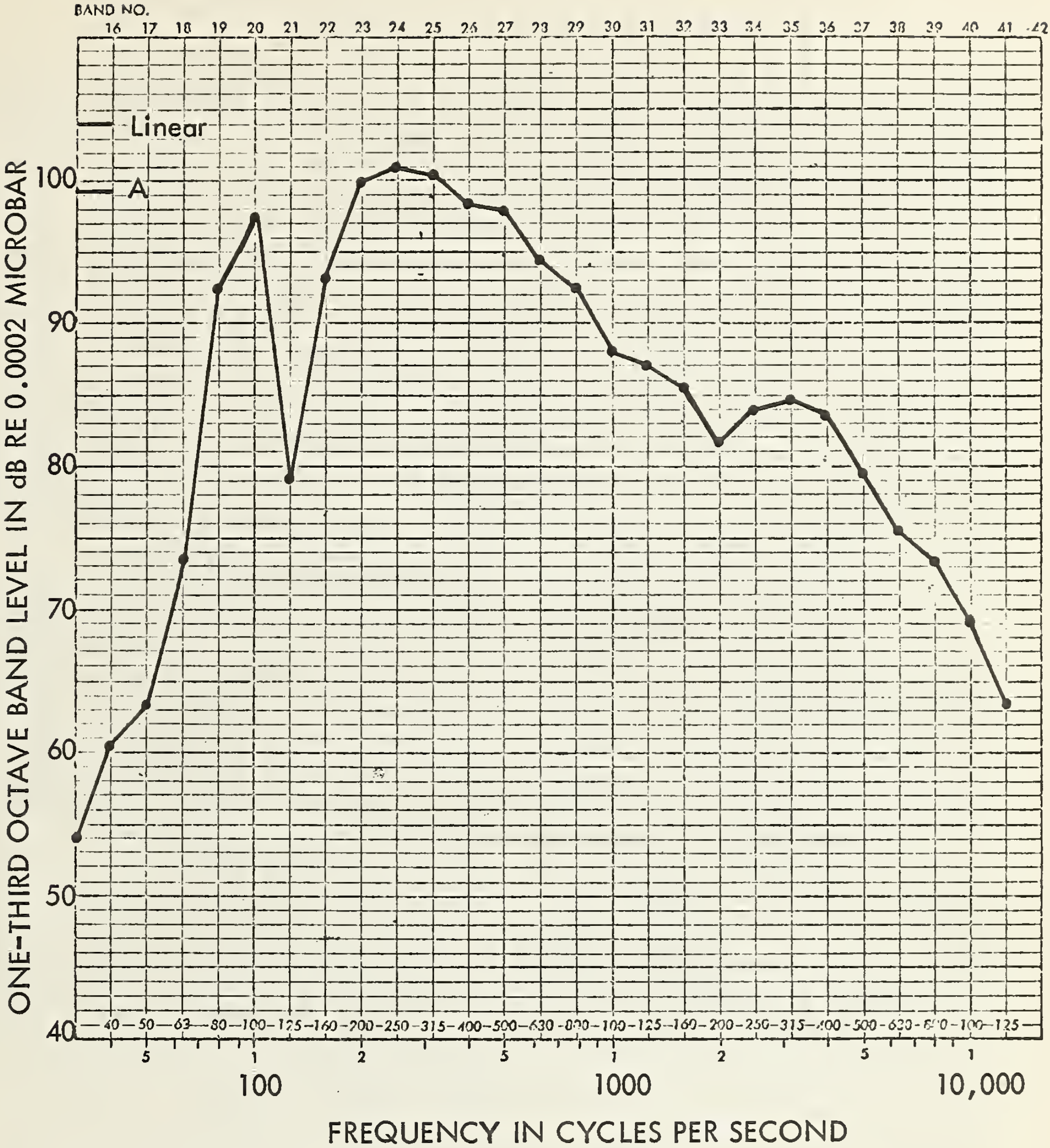
1971 Moto-Ski 399
Average of 2 runs



Ski-Whiz
Average of 3 runs



1969 Mercury 250-E
Average of 3 runs



1967 Sno-Jet 125
Average of 3 runs

APPENDIX II

SNOWMOBILE DETECTABILITY PREDICTION METHOD

APPENDIX II

SNOWMOBILE DETECTABILITY PREDICTION METHOD 1/

A study completed by Bolt, Beranek, and Newman for the Air Force (17) provides a means for determining the level of a signal which is detectable in the presence of background noise. A special graph was prepared to facilitate determination of the level at which a noise source will be detectable with specified probabilities. Figure 2-1 embodies the assumptions of 50 percent detectability and 1 percent false alarm rate. A false alarm occurs when the subject states that he heard a noise when in fact none was presented. Thus a 1 percent false alarm rate implies a fairly strict requirement that the listener has really heard the noise instead of just guessing whether he heard it. The plot of hearing threshold in figure 2-1 may be interpreted as the level at which the average human observer is capable of detecting a signal 50 percent of the time in the absence of external background noise. Naturally no signals below this line would be detectable 50 percent of the time. Figure 2-1 also includes a special set of ordinates (indicated by the sloping grid lines) for use in plotting the background noise spectrum in 1/3 octave bands. When the background noise is plotted on the special grid of Figure 2-1 it may be used (in conjunction with pure tone threshold) to produce the predicted 1/3 octave band detection levels.

Figure 2-2 shows an example of the technique used to determine levels at which the snowmobile would be detectable 50 percent of the time at various distances. First the background noise level is plotted using the slanted grid lines. This spectrum was determined in the Sespe Wildlife Area (8). Next, the average spectrum of the 1972 Ski-Doo TNT's tested was determined as a function of distance. At 50 ft, this snowmobile produces 92 dBA, when tested by the Forest Service screening procedure. To calculate the 1/3 octave band sound pressure spectrum as a function of distance, it was assumed that excess attenuation due to ground cover and trees was 10 dBA, and that the effects of scattering, atmosphere gradients, and shielding could be ignored (5, 11). Beranek's experimental data for molecular absorption in air were used (2). The spectra at the various distances were compared to the background spectrum. If any part of the snowmobile spectrum at a given distance was higher than the background spectrum, then the snowmobile was assumed to be detectable more than 50 percent of the time. When any point on the snowmobile spectrum was just tangent to the background spectrum, then the distance associated with this spectrum was taken as the "vanishing distance", or that distance at which the snowmobile would be detectable 50 percent of the time, with a 1 percent false alarm rate. This distance turned out to be 11,000 ft for the 92 dBA snowmobile. The spectrum of the snowmobile at 11,000 ft is shown on figure 2-2. In a like manner, the vanishing distance for the 1971 Ski-Doo Elan, 83 dBA at 50 ft, was calculated to be 6,200 ft. For a hypothetical 73 dBA at 50 ft snowmobile with the same spectral shape as the Elan, the vanishing distance was found to be only 2,800 ft.

1/ This appendix was prepared with the cooperation of Dr. Karl Pearsons, of Bolt, Beranek, and Newman. His assistance is gratefully acknowledged.

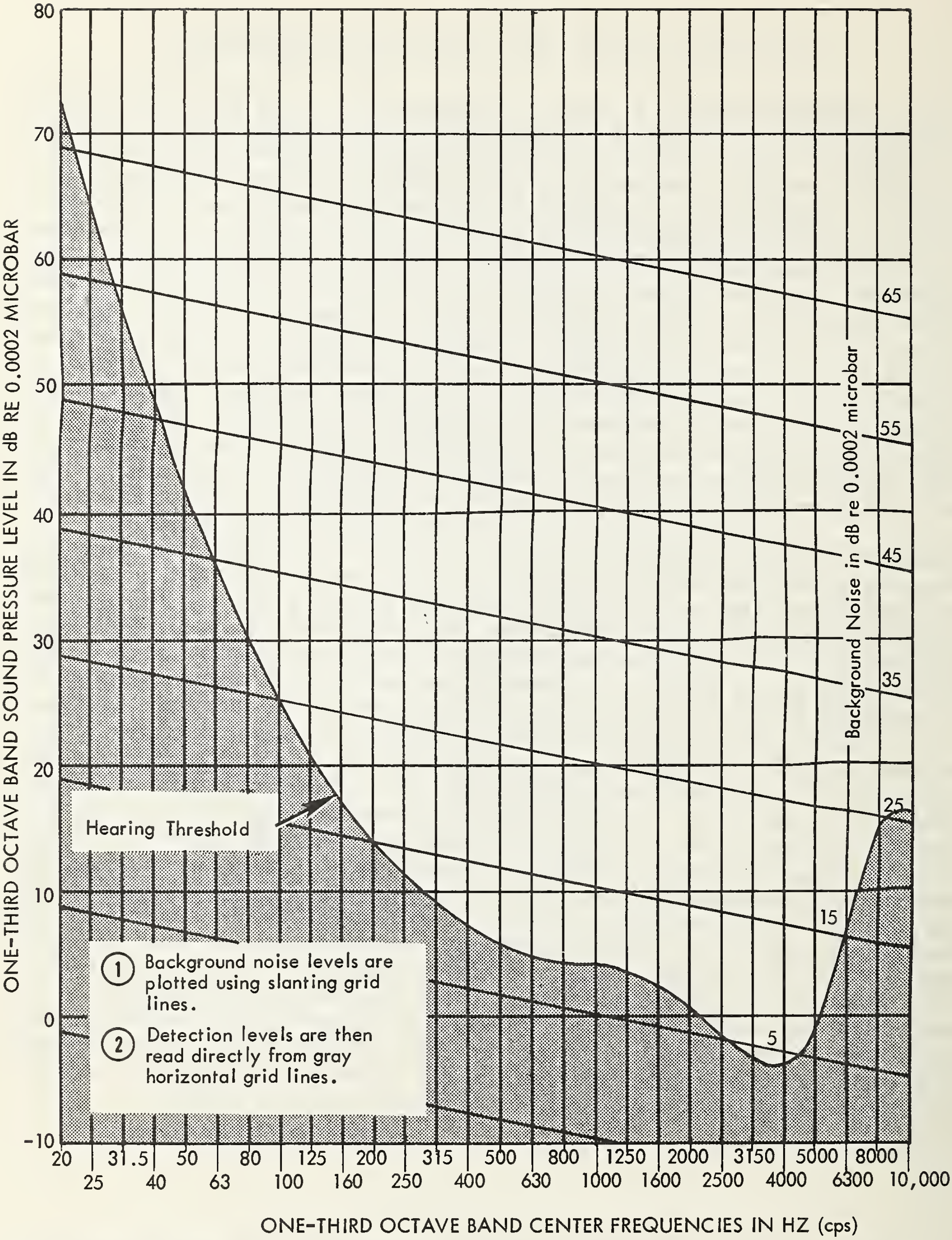


Figure 2-1. Chart for predicting detection levels (for 50% correct and 1% false alarm rates) using background noise spectrum in one-third octave bands.

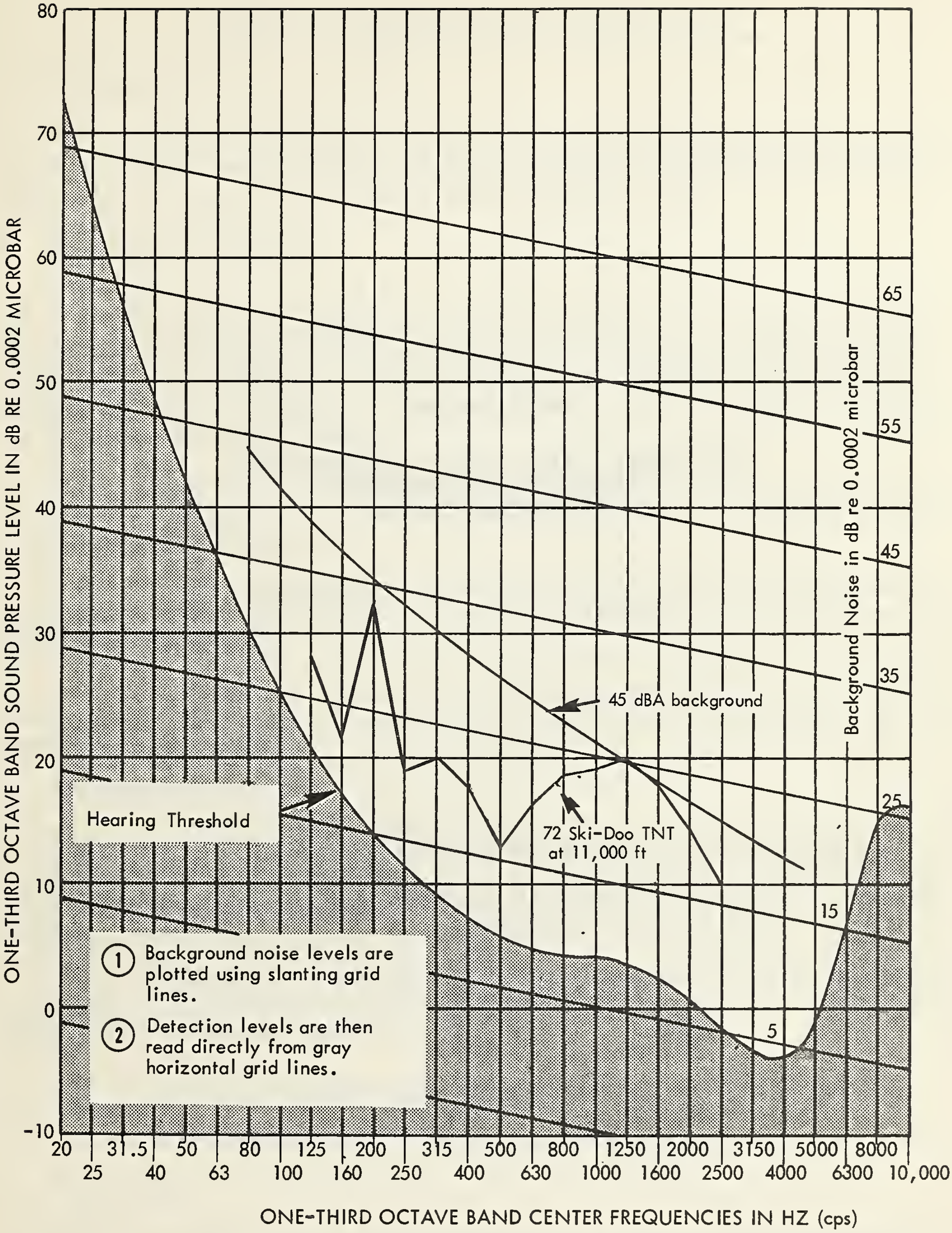


Figure 2-2. Detectability prediction chart, showing spectra of background and snowmobile.

APPENDIX III

PROPOSED SOUND LEVEL STANDARD AND WINTER TEST PROCEDURE FOR SNOWMOBILES

APPENDIX III

PROPOSED SOUND LEVEL STANDARD AND WINTER TEST PROCEDURE FOR SNOWMOBILES

1. INTRODUCTION

This standard describes sound level limits for snowmobiles used on National Forest lands. This test procedure establishes methods and describes the test environment and instrumentation for determining these sound levels.

2. SOUND LEVEL LIMITS

2.1 All snowmobiles operated on National Forest lands must be equipped at all times with an exhaust muffler equivalent in performance to at least the manufacturer's original equipment. When a snowmobile has been sold without an exhaust muffler, silencing equipment must be installed, including but not limited to an exhaust muffler, so as the total sound level, measured by the method described herein, does not exceed 92 dBA.

2.2 All snowmobiles operated on National Forest lands, which were sold new after June 1, 1972, must not produce more than 82 dBA, when measured by the method described herein.

2.3 All snowmobiles operated on National Forest lands, which were sold new after June 1, 1975, must not produce more than 78 dBA, when measured by the method described herein.

2.4 All snowmobiles operated on National Forest lands, which were sold new after June 1, 1980, must not produce more than 73 dBA, when measured by the method described herein.

3. INSTRUMENTATION

The following instrumentation shall be used for the measurement required:

3.1 A sound level meter which meets the requirements of American National Standards Institute S1.4-1971, General Purpose Sound Level Meters.

3.1.1 Alternatively, a microphone/magnetic tape recorder/indicating meter system whose overall response meets SAE Recommended Practice J184, "Qualifying a Sound Data Acquisition System."

3.2 A sound level calibrator (see paragraph 5.5).

3.3 A calibrated windscreen or nose cone (see paragraph 5.4).

4. PROCEDURE

4.1 TEST SITE - A test site suitable for the purpose of measurements shall consist of a flat open space free of large reflecting surfaces such as signboards, buildings, or hillsides located within 50 ft of either the vehicle or the microphone. Other site limitations shall be as shown in figure 1.

4.1.1 The surface of the ground within the measurement area shall be covered with snow.

4.1.2 Because bystanders may have an appreciable influence on meter response when they are in the vicinity of the vehicle or the microphone, not more than one person other than the observer reading the meter shall be within 50 ft of the vehicle or microphone, and that person shall be directly behind the observer reading the meter, on a line through the microphone and the observer.

4.1.3 The ambient sound level (including wind effects) due to sources other than the vehicle being measured shall be at least 10 dBA lower than the level of the tested vehicle.

4.1.4 The path of vehicle travel shall be relatively smooth.

4.1.5 The microphone shall be located 50 ft from the centerline of the vehicle path at a height of 4 ft above the ground plane.

4.1.6 An acceleration point (point A) shall be established on the vehicle path 25 ft before a line through the microphone and normal to the vehicle path.

4.2 VEHICLE OPERATIONS

4.2.1 The vehicle shall proceed along the test path at a constant approach speed of 25 mph. When the front of the vehicle reaches the accelerating point, the throttle shall be opened wide, and maintained until the front of the vehicle is 25 ft beyond the microphone.

4.3 MEASUREMENTS

4.3.1 The meter shall be set for "fast" response and for the A-weighted network. If the meter is equipped with "hold", it may be used, provided the response time is identical to that used on "fast." ("Impulse" may <u>not</u> be used.)

4.3.2 The meter shall be observed while the vehicle is accelerating. The applicable reading shall be the highest sound level obtained for the run, ignoring unrelated peaks due to extraneous ambient noises. Sufficient preliminary runs to familiarize the driver and to stabilize the engine operating conditions shall be made before measurements begin. Immediately after the preliminary runs, at least two measurements shall be made for each side of the vehicle. All of the values shall be recorded.

4.3.3 The sound level for each side of the vehicle shall be the average of the two highest readings which are within 2 dB of each other. The sound level reported shall be that of the louder side of the vehicle.

5. GENERAL COMMENTS

5.1 It is strongly recommended that technically trained personnel select equipment and that tests be conducted only by qualified persons trained in the current techniques of sound measurement.

5.2 An additional 3 dBA allowance over the sound level limit is recommended to provide for variations in test site, vehicle operation, temperature gradient, wind velocity gradients, test equipment, and inherent differences in nominally identical vehicles.

5.3 Instrument manufacturer's specification for orientation of the microphone relative to the source of sound and the location of the observer relative to the meter should be adhered to.

5.4 When a windscreen is required, a previously calibrated windscreen should be used. It is recommended that measurements be made only when wind velocity is below 12 mph.

5.5 Instrument manufacturer's recommend calibration practice should be followed. Field calibration should be made immediately before and after each test sequence. Either an external calibrator or internal calibration means is acceptable for field use, provided that external calibration is accomplished immediately before or after field use.

6. REFERENCE MATERIAL

Suggested reference material is as follows:

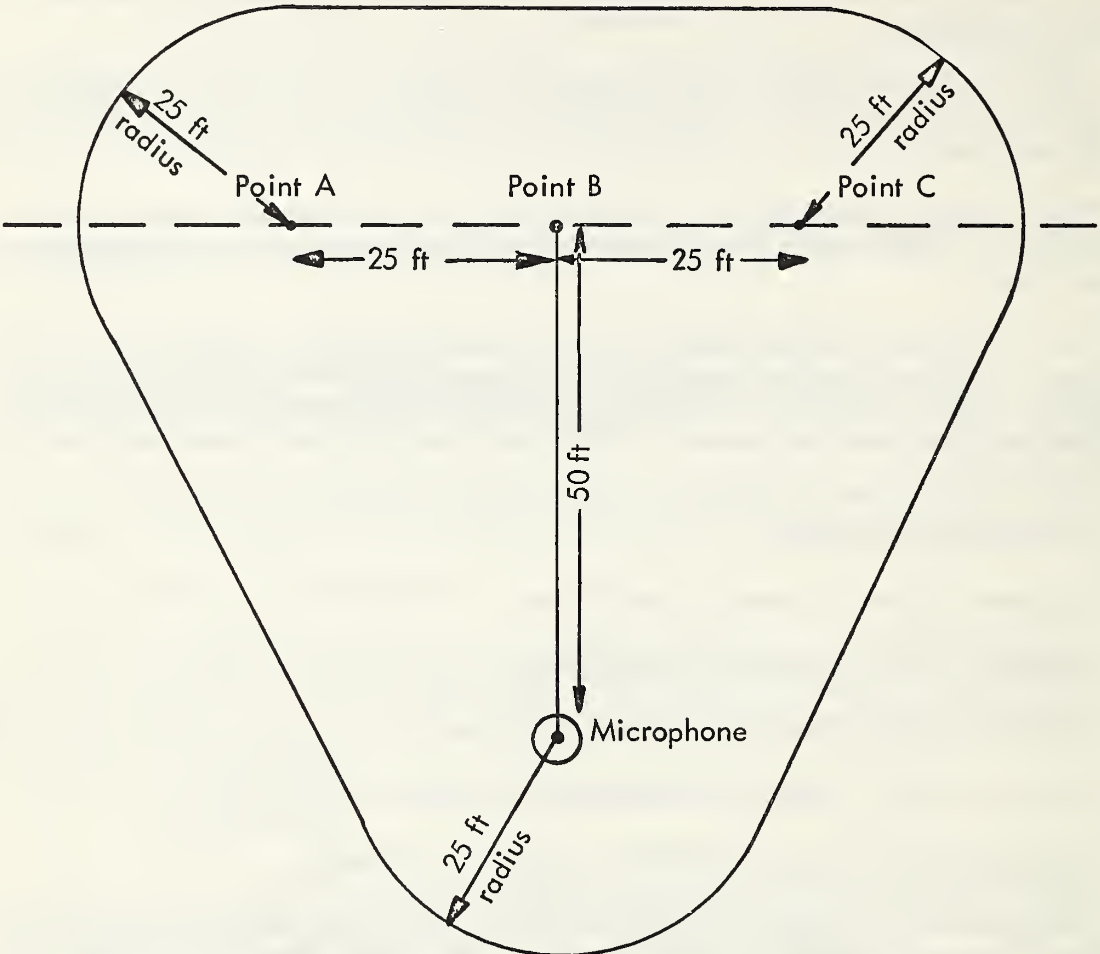
ANSI S1.1-1960, Acoustical Terminology.

ANSI S1.2-1962, Physical Measurement of Sound.

ANSI S1.4-1971, Standard Specification for Sound Level Meters.

SAE J184, Qualifying a Sound Data Acquisition System.

(Applications for copies of these documents should be addressed to American National Standards Institute, 1430 Broadway, New York, New York, 10018, and the Society of Automotive Engineers, 2 Pennsylvania Plaza, New York, New York 10001).



COURSE REQUIREMENTS

Uniform level course between points A & B.

No obstructions within boundary shown.

No obstructions higher than 3 ft within 50 ft of points A, B, & C, or microphone.

Diagram, drive-by test course.

GPO 873-025